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EXTERNALLY GENERATED LIGHT (EGL) SYSTEMS FOR HYPERBARIC/HYPOBAR--ETC(U)
JAN 77 K O GRAY

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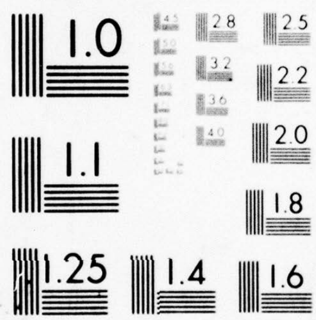

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Lighting systems for hyperbaric/hypobaric chambers are described. Methods of interior illumination without introduction of any potential fire source in the chamber are presented. The systems utilize light generated outside of the chamber environment, filtered for reduction of infrared radiation, and then introduced through either large (viewport sized) or small (pipe sized) transparent hull penetrations. Accessory devices for use with externally generated lighting (EGL) systems are also described.

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INTRODUCTION

The Naval Facilities Engineering Command (NAVFAC), between 1967 and 1975, has sponsored the development of safe certifiable designs for acrylic windows for use in externally pressurized undersea systems and internally pressurized vessels [1-7]. During the past few years this technology has been applied to the design of viewport systems for manned hyperbaric chambers for diver research, medical treatment, and diver recompression.

The hyperbaric chamber lighting investigation reported herein was an extension of the viewport program and was directed toward developing techniques for utilizing viewports as transparent pressure-resistant penetrations for safe introduction of externally generated light (EGL) into the interior of manned chambers. Two types of EGL systems were developed. One was designed to use large viewports which may be alternatively used for optical viewing. A second, an acrylic light pipe (ALP) system was designed to use smaller, pipe-sized penetrations with alternative function, such as introducing gas, fluid, and power, into chambers.

The reasons for illumination inside a hyperbaric chamber are many. One is the basic psychological requirement to provide sufficient light for the humans occupying the chambers to avoid the claustrophobic effect from confinement in a totally dark tank. Additionally, the chamber operators must be able to observe the occupants for any reaction they may have to their environment to insure their well-being. Further, if the occupants are required to participate in the ongoing work, they must be able to see what they are doing. During extended ‘‘dives’’ the chamber occupants must carry on the day-to-day routines of eating, sleeping, and working, which, of course, requires a variety of lighting conditions and levels appropriate to the ongoing activity.

While the need for internal illumination is easily understood, the desirability of externally located lights is not so obvious. Diver recompression chambers have been in service for many years and, when useful light was desired inside the chamber, standard procedure was to wire in an ordinary incandescent lamp through a stuffing tube. With the pressures and atmospheres normally used in these early chambers, this method was generally satisfactory though not safe by today's safety standards. The higher internal pressures and the nature of atmospheres used in modern research and recompression chambers for supporting deep diving work have considerably altered the mechanical requirements for electrical penetrations and internal lighting systems as well as for the chamber itself.

As a result of the tragic fire in the APOLLO capsule (a hyperbaric chamber operating at 16.2 psi with a pure oxygen atmosphere) an extensive study was undertaken to explore the hazards of accidental fires with

such chambers. One of these studies [8], covering 11 fires in both hyperbaric and hypobaric chambers, stated that 10 were ignited by an electrical source, 4 of which were related to electric lamps. These findings indicated, among other things, that it would be desirable to exclude electric lamps and as many other electrical appliances as possible from these chambers. This, then, led to the development of EGL systems with power and control operation entirely outside the chamber.

CHAMBER LIGHTING PRACTICE

Basic Options for Location of Light Sources

Internally located light sources are the traditional type and are still the most frequently encountered. They can be the least costly since for low-pressure chambers using normal air composition, small, relatively inexpensive, pipe-sized stuffing tubes can serve to pass the electrical conductors through the hull. In many cases commercially available components, orginally intended for other purposes, are used for assembling in-board systems. Some highly refined systems of this basic type are successfully used at high pressures with mixed gases. These systems use custom-fabricated fixtures, special high pressure lamp enclosures, mineral-filled electrical conduits vented outboard, and other well-engineered, built-in safety precautions.

A second version of the internally located light source is used in at least one large medical chamber. This system utilizes transparent, pressure-resistant enclosures which protrude into the chamber. The interior of these enclosures is open to the atmosphere surrounding the chamber. This allows a light source to be physically inside the chamber hull boundary; but, at the same time, not be exposed to the interior environment. This permits changing of burned-out lamps by externally located support personnel and eliminates the possibility of a lamp filament's igniting an explosive atmosphere or other combustibles in the chamber.

Light sources external to the chamber range from as simple a device as a spotlight directed through a large viewport to one as sophisticated as an acrylic light pipe or fiberoptic system utilizing small pipe-sized penetrations.

Chamber Lighting Systems

United States Navy. The standard Navy aluminum, double-lock recompression chamber, was designed for 100-psi maximum operating pressure and for utilizing an internally located incandescent lamp system. This system (Figure 1) uses a standard Navy, clear marine navigational light enclosure inside of which a 115-volt AC double-filament lamp is located. A specially designed base is provided so that a pressure-tight seal is obtained with the hull.

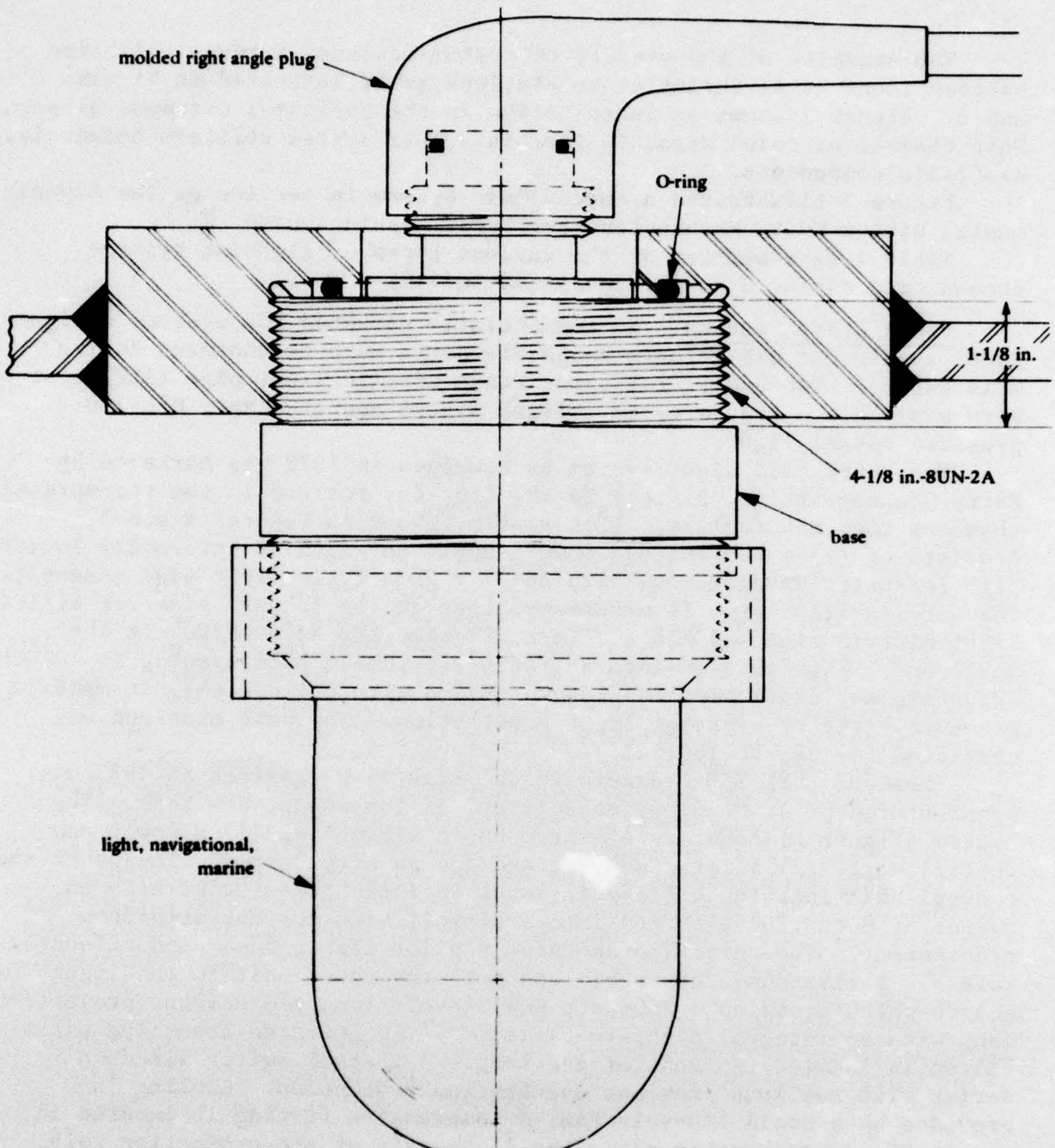

Figure 1. Internally located incandescent lighting system used in standard Navy aluminum double-lock recompression chambe.

Two examples of the variety of custom-designed external lighting systems found at different shore stations are illustrated in Figures 2 and 3. Figure 2 shows an installation on the Explosive Ordnance Disposal Unit chamber at Point Mugu, California. This system utilizes commercially available components.

Figure 3 illustrates a custom-made system in service at the Experimental Diving Unit, Washington Navy Yard, Washington, D. C.

Table 1 is a summary of the various types of lighting systems encountered during a survey conducted in 1972.

Proprietary Systems. No commercially marketed EGL systems designed specifically for use through large viewports were encountered during this survey. Two commercial proprietary acrylic light pipe (ALP) systems were available - the Perry cold light system and the Canty HYL-250 pressure vessel light.

The Perry cold light system as examined in 1972 was marketed by Perry Oceanographics, Riviera Beach, Florida, for use in the recompression chambers they manufacture. This system, shown in Figures 4 and 5, consists of (1) a low voltage power supply to drive an externally located high intensity bayonet base lamp and (2) an acrylic light pipe assembly. The acrylic light pipe is mushroom-shaped on the inboard side for efficient light distribution and has a 1-inch NPT male thread machined on the small end. When screwed into a 1-inch NPT female hull opening (a 1-inch NPT stainless steel pipe coupling provided with the system), it makes a pressure tight transparent light penetration. The unit examined was certified for use to 180 psi.

The Canty HYL-250 Pressure Vessel Light* as examined in 1972 was manufactured by J. M. Canty Associates, of Tonawanda, New York. The system (Figure 6) consists of three basic assemblies (1) a power and control unit, (2) a light source, and (3) an acrylic rod. The power and control unit contains a 115-volt input variable transformer with an output of 0 to 120 volts fed into a 24-volt high-current step-down transformer. The unit also contains a pilot light, fuse, and off-on switch. A five-conductor cable connects the power unit to the light source which contains a 250-watt EKS 24-volt tungsten halogen projection lamp with an integral dichroic reflector. An infrared absorbing glass filter is located in front of the lamp. A thermal switch wired in series with the lamp provides overheating protection. Cooling is provided by a small 110-volt fan. A compression fitting is located in the light source housing along the light axis of the projection bulb. This fitting couples the light source assembly to the acrylic light pipe (ALP) (see Figure 7).

Figures 8 and 9 illustrate the installation method used with this system at New York University. The conical sealing section seats in a mating penetration fitting that is then screwed into a 1-1/4-inch NPT pipe thread on the outboard side of the hull. This chamber is designed for a maximum operating pressure of 2,500 psi.

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*U. S. Patent No. 3,813,514.

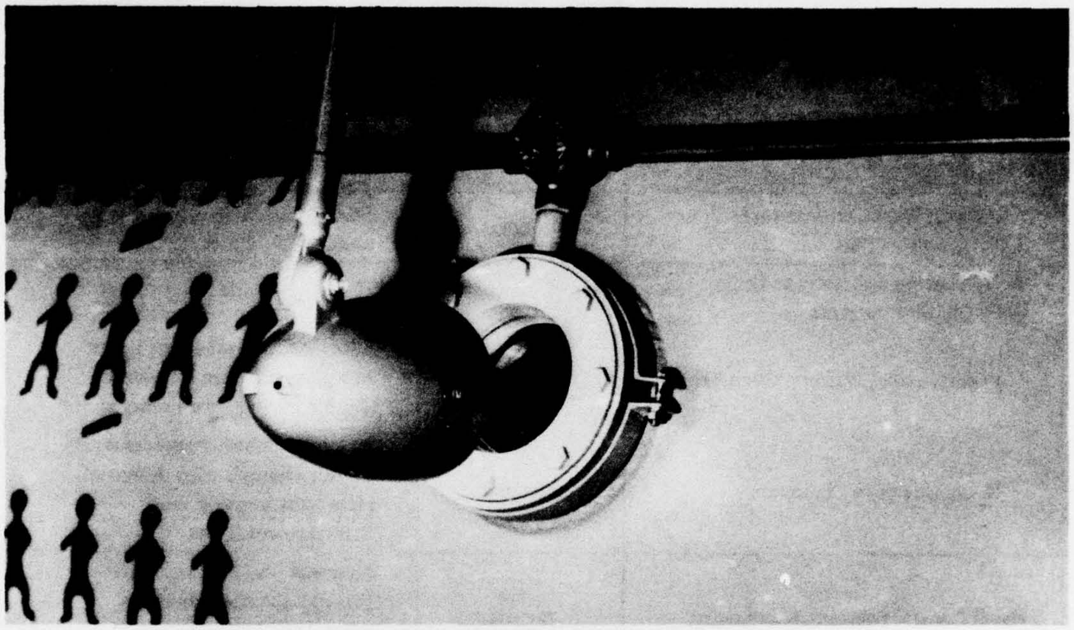

Figure 2. Custom-made externally located incandescent lighting system used at Explosive Ordnance Disposal Unit, Naval Air Station, Point Mugu, California.

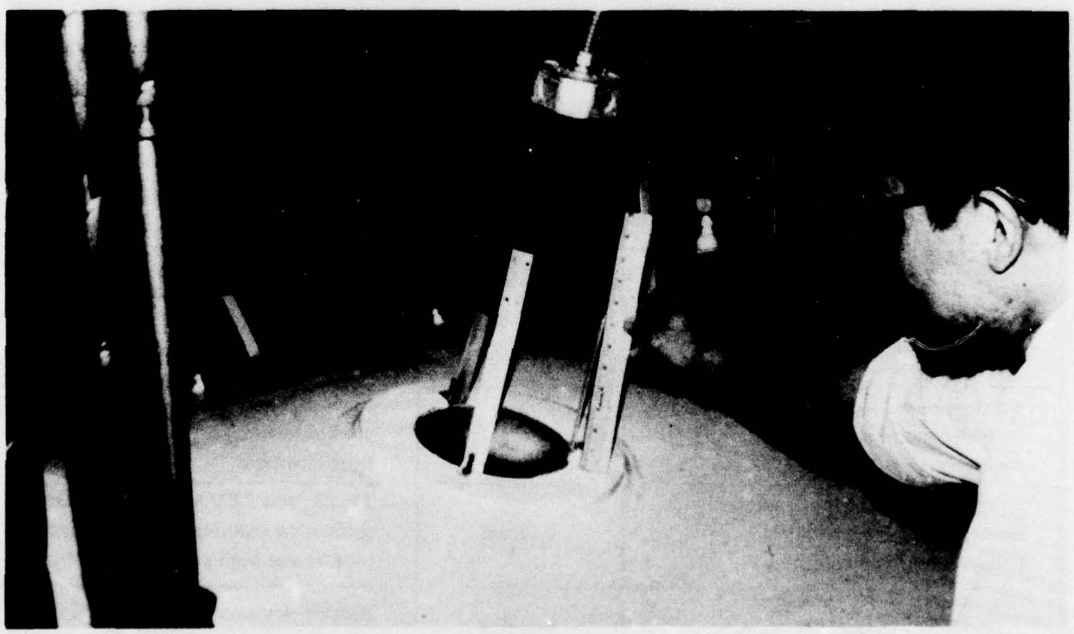

Figure 3. Custom-made externally located incandescent lighting system used at Experimental Diving Unit, Washington Navy Yard, Washington, D. C..

Table 1. Summa.y of the Illumination Systems Encountered During a Survey of Hyperbaric Chambers in 1972

Facility	Location of Light Source	Type of Light Source[a]
Southwest Research Institute San Antonio, Texas	Internal	EG&G high intensity underwater lights
Taylor Diving and Salvage Co. Belle Chase, Louisiana		
Research and Training Chamber	Internal	120 VAC incandescent lights in a glass pressure housing of Taylor Diving's own design
Recompression Chambers	Internal	Recompression chambers with Taylor Diving's own design of glass light housings and incandescent lights
Naval Coastal Systems Laboratory Ocean Simulation Facility Panama City, Florida	Hybrid Internal and External	External low voltage lights through regular viewports when chamber is operating in fire danger zone and internal incandescent when not in fire danger zone
Environmental Research Laboratory Duke University Raleigh, North Carolina	Internal	120-VAC incandescent lights in standard submarine running light housings and also low voltage incandescent automobile type light bulbs
Naval Experimental Diving Unit Washington, D. C.	External	110 VAC incandescent lights with infrared filter operating through regular viewports
Naval Medical Research Institute Bethesda, Maryland	Internal	Incandescent lights in standard submarine running light housings
Naval School of Diving and Salvage Washington, D. C.	Internal	Incandescent lights in standard submarine running light housings
Westinghouse Ocean Research and Engineering Center Anapolis, Maryland	Internal	Incandescent lights in standard commercial explosion-proof light housings
Institute for Environmental Medicine University of Pennsylvania Philadelphia, Pennsylvania	Internal	12, 28, and 32 VAC lights are used; submarine running light housings are used in the high pressure chamber
Department of Physiology State University of New York Buffalo, New York	External	Proprietary acrylic pipe light (Canty Light) is used

[a]In addition to primary general illumination systems, all chambers have intermittent requirements for special purpose lights which range from high intensity lights for color photography to hand-held battery-powered flashlights.

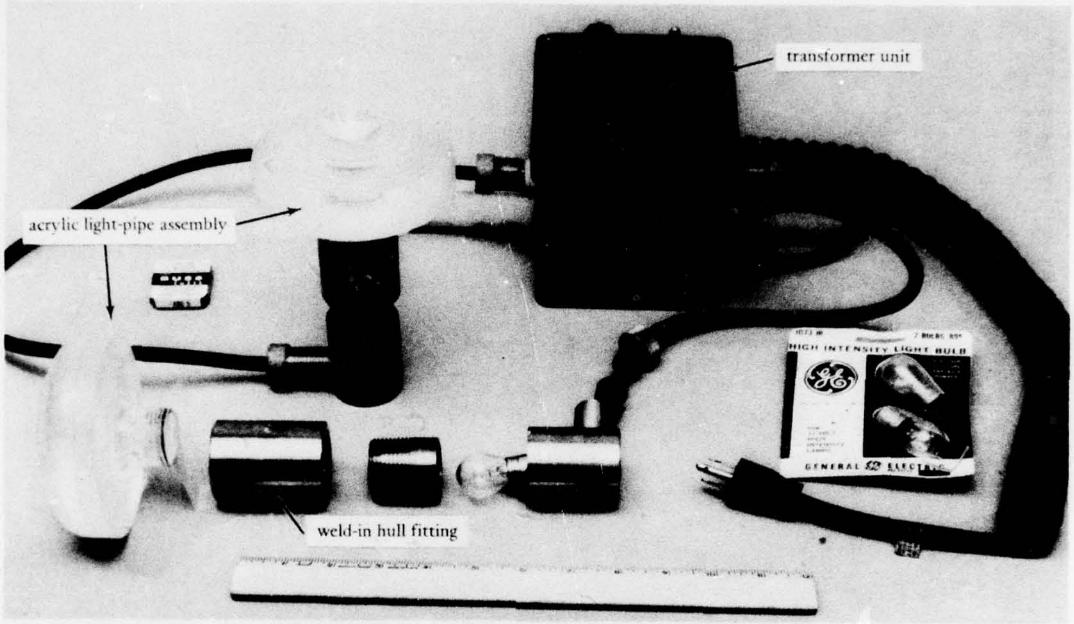

Figure 4. The components of a typical Perry cold light system.

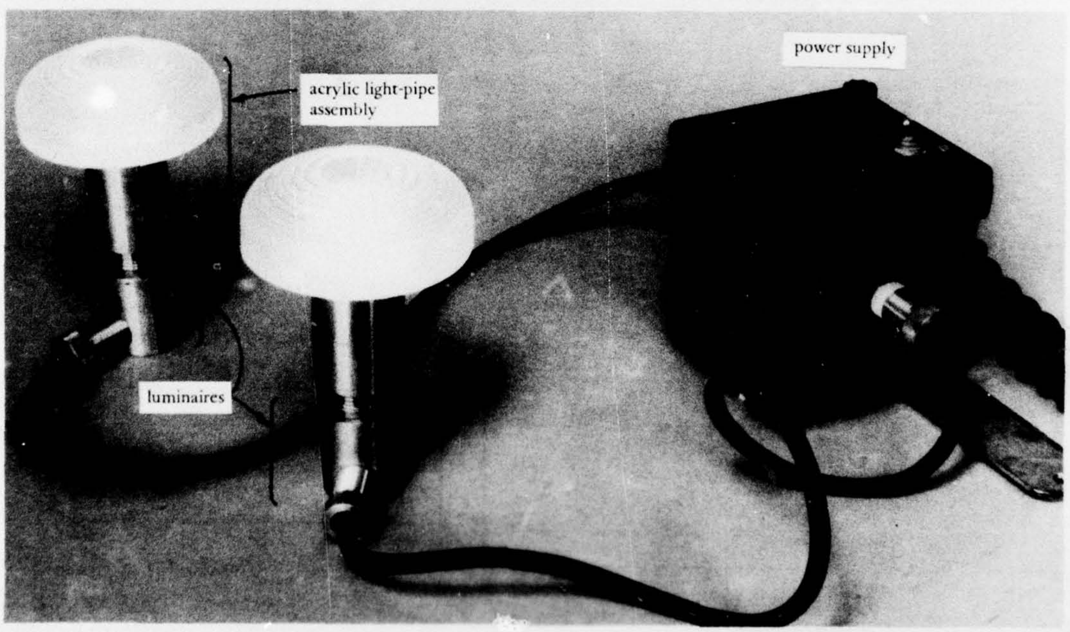

Figure 5. The Perry cold light system showing the power supply, the luminaires and the acrylic light-pipe assemblies.

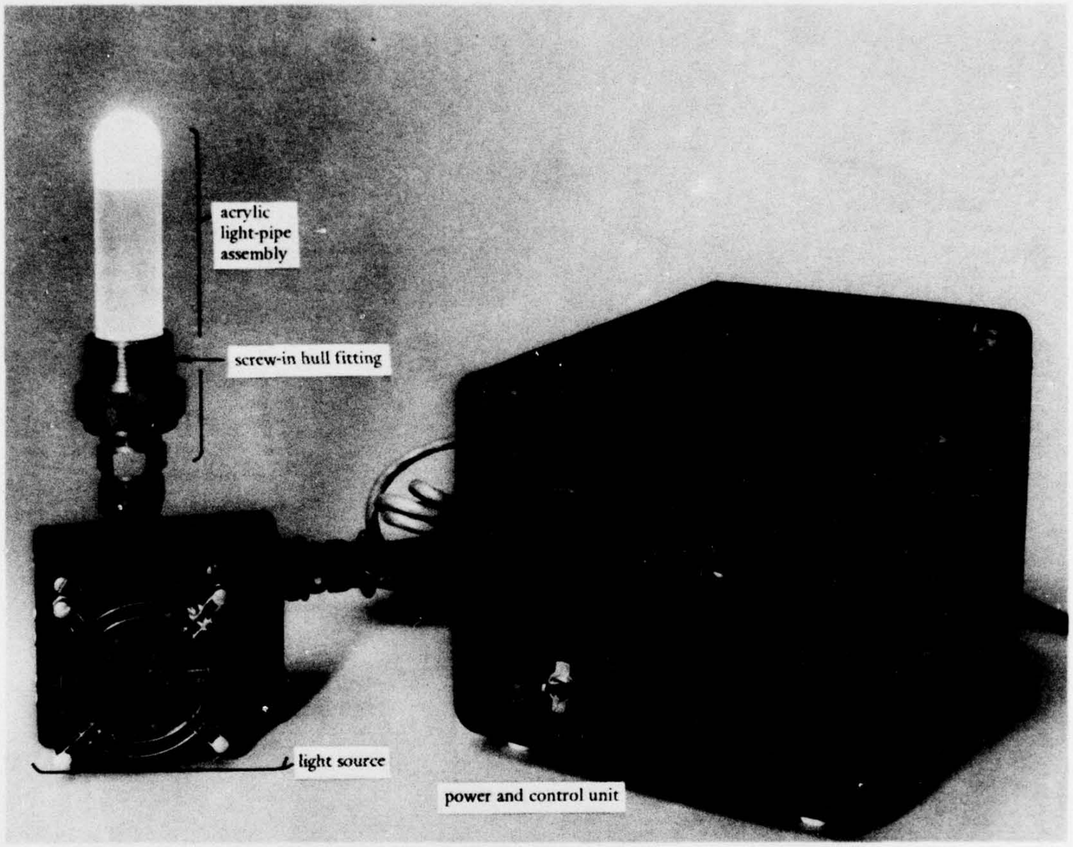

Figure 6. Canty Model HYL-250 Pressure Vessel Light system (U. S. Patent No. 3,813,514).

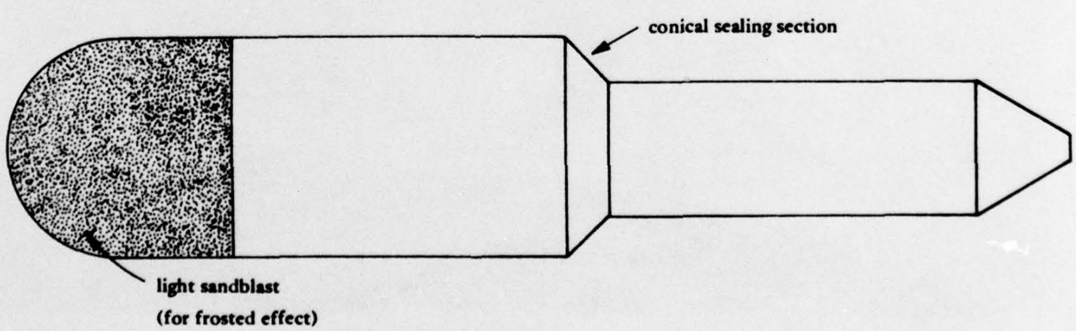

Figure 7. Acrylic pipe light of clear, cast acrylic rod provided with Canty HYL-250 pressure vessel light (U. S. Patent No. 3,813,514).

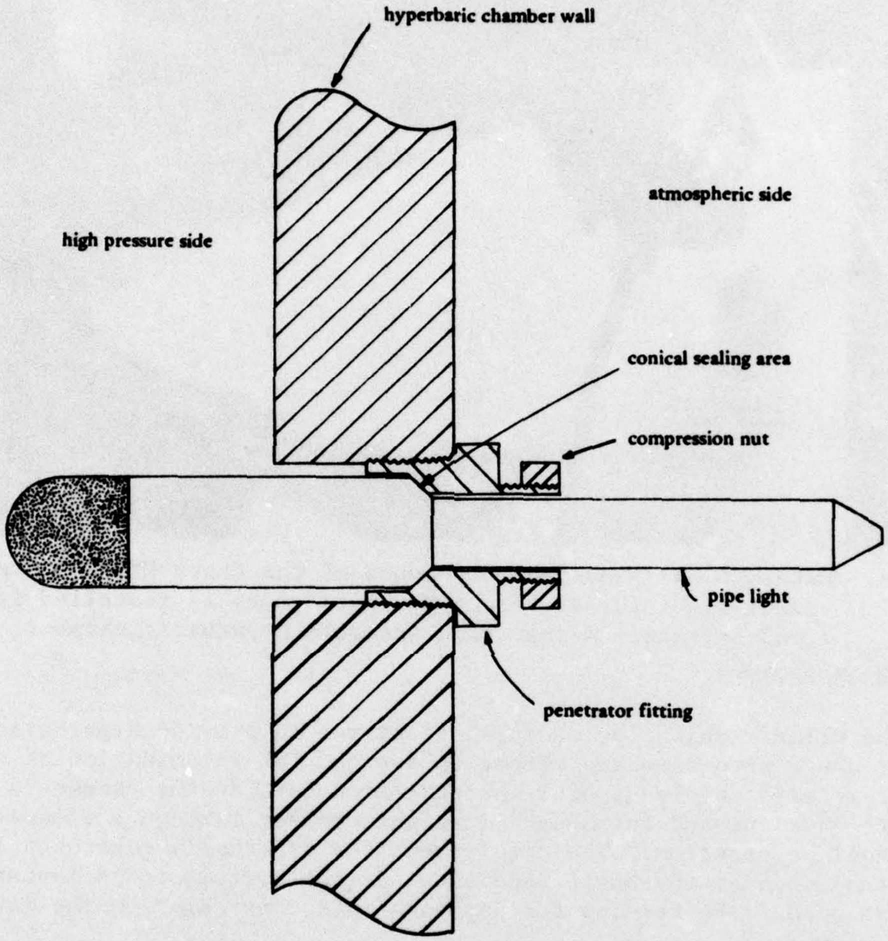

Figure 8. Method of installing Canty HYL-250 pressure vessel light (U. S. Patent No. 3,813,514) at New York State University.

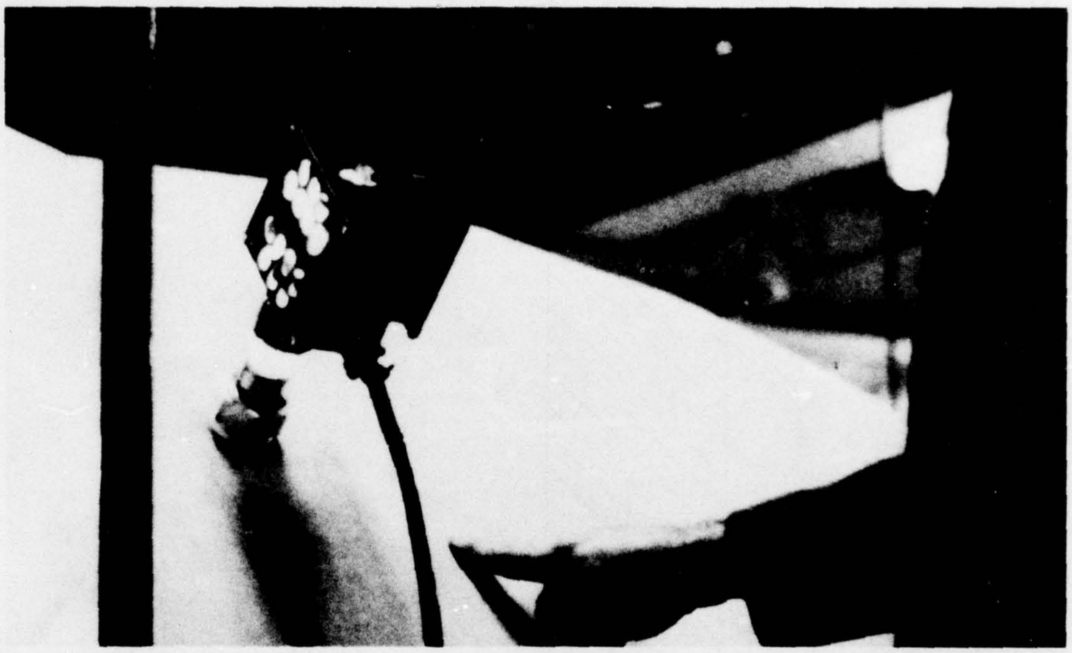

Figure 9. External hull-mounted components of the Canty HYL-250 pressure vessel light (U. S. Patent No. 3,813,514) as installed in a 2,500-psi-maximum operating pressure hyperbaric chamber.

PROGRAM OBJECTIVES

The primary objective of this effort was to provide hyperbaric chamber users with safe and effective systems for illumination of the chamber interior by means of light generated outside the chamber's pressure envelope and introduced into the chamber through a viewport or other hull penetration. The requirement for externally generated light was established as the basic requisite for the systems to be investigated and developed. The reasons for imposing this constraint on the investigation were to:

1. Eliminate the fire hazard which internally located electric lamps have been shown to present.

2. Reduce the electrical power circuits in chambers to an absolute minimum.

3. Reduce the number of electrical penetrations through the chamber pressure envelope.

4. Eliminate a source of unwanted waste heat in the chamber.

5. Relieve the fire protection sensors of as much extraneous infrared as possible.

6. Eliminate the potential hazard presented by a light bulb or pressure housing which might explode during decompression as a result of gas embolism.

As a result of the study of the various lighting systems discovered during the state-of-the-art survey and many discussions with chamber users and operators, certain lighting system designs and operational characteristics were identified and cataloged as desirable or undesirable. In addition to these characteristics, which were largely based on the use of glass as the viewport material, a set of new factors was introduced by the increasing use of polymethyl-methacrylate (acrylic plastic) as the viewport material.

The principal new consideration introduced by the use of acrylic plastics is the sensitivity of the viewport to overheating. Acrylic viewports are relatively insensitive to thermal shock, but indiscriminate placement of high intensity lights can degrade their operational safety if the surface temperature of the viewport exceeds 150°F.

Based on the foregoing considerations, generalized performance objectives were evolved and used as guidelines in the development of the large viewport and acrylic light pipe EGL systems.

Large Viewport EGL Development Guidelines

The desired system will safely deliver general purpose illumination to the chamber interior without electrical power or control circuitry for lighting inside the pressure envelope. In addition, the desired system will also meet the following criteria:

1. An existing large viewport shall be used without requiring any structural modification.

2. The power source will be 115 volts AC.

3. Commercially available light sources (bulbs) will be utilized.

4. The surface temperature of the viewport being used shall not exceed 120°F or 150°F after 8 or more hours of continuous operation in an ambient air temperature of 70°F or of 90°F, respectively.

5. The attachment system for the EGL assembly will utilize clamps or other methods not requiring modification to the viewport mounting system or chamber.

6. The installation, removal, operation, or maintenance of the unit shall not affect the pressure integrity of the viewport or interrupt continuous chamber operation.

7. The luminary attachment system shall be easily moved away by hinge or pivot from the viewport to permit viewing, without requiring the viewer to use any tools.

8. Light bulbs shall be easily and rapidly replaced without any tools.

9. The system shall be electrically safe and certifiable under the appropriate regulations.

Small Penetration (ALP) EGL Development Guidelines

As with the large viewport EGL development guidelines, the desired system will safely deliver general purpose illumination to the chamber interior without electrical power or control circuitry for lighting inside the pressure envelope. In addition, the desired system will also meet the following criteria:

1. Existing penetrations in the pressure envelope shall be used without requiring any structural modification.

2. Small pipe-sized penetrations other than those intended for viewports shall be used.

3. The surface temperature of the transparent pressure sealing element (window) in the light/chamber penetration system shall not exceed $120^{o}F$ or $150^{o}F$ after 8 or more hours continuous operation in an ambient environmental temperature of $70^{o}F$ or of $90^{o}F$, respectively.

4. The transparent pressure sealing element must be certifiable under requirements of Reference 10.

5. The structural and pressure integrity of the transparent pressure sealing component and the overall system must not be sacrificed by intentional or accidental removal or damage to any portion of the system which projects from the outboard - or low pressure side of the chamber wall.

6. Any part of the subsystems that is outboard of the transparent pressure sealing component shall be safely and easily repaired or replaced without violating the structural or pressure integrity of the chamber.

7. The occupants shall be able to employ various light distribution options that can be changed at any time without using special tools and without altering the structural or pressure sealing integrity of the chamber.

LARGE VIEWPORT EGL DEVELOPMENT

Light Source

The primary technical problem involved in the design of a satisfactory EGL system revolved around the selection of the optimum light source. The factors of importance in light source included:

1. An adequate flux of light

2. A light of a spectral distribution that the human eye could most efficiently utilize

3. A ''comfortable'' color light

4. Maximum light with minimum heat

5. Instant response when turned on
6. Dimming capability
7. Modest cost
8. Ready commercial availability
9. Good life expectancy
10. Absence of toxic chemicals

After an extensive survey of the available light sources and the assistance of illumination experts of the major lamp manufacturers, the choice was narrowed to a family of so-called PAR reflector-type lamps with a ''dichroic'' reflector coating. This unique multilayer metallic reflector coating acts as a selective reflector in that it transmits infrared (heat) rays and reflects light rays in the visible wavelengths. The net result is that a 150-watt PAR lamp with a dichroic reflector delivers about the same flux of visible light as a similar lamp with a conventional aluminized reflector, but delivers only about one-third the radiant thermal energy as the conventional reflector lamp. Lamps of this type are widely used in the food and merchandising industry where ''hot'' light cannot be tolerated.

Lamps of this type are manufactured by General Electric under the trade name of ''Cool-Beam'' and by Sylvania under the trade name ''Cool-Lux.'' The 150-watt dichroic reflector PAR-38 lamp, carried in the Federal Stock Catalog under FSN 6240-958-6656 or FSN 6240-958-9761 is the lamp selected for use in the large viewport EGL unit.

This tungsten filament incandescent lamp is instant lighting and can be easily dimmed by use of a rheostat or solid state dimmer. These lamps have a rated life of 2,000 hours and deliver approximately 1,730 initial total lumens and 4,200 candlepower. The list price in 1974 ranged between $6 and $7 each.

Heat Extraction

While the dichroic reflector light source delivers substantially less heat than conventional reflector lamps, more heat than is desirable is still delivered by direct radiation from the tungsten filament, which operates in the range of 4,000 to 5,400°F. To keep the EGL system as small as possible because space around hyperbaric chambers is generally at a premium, it was desirable to locate the lamp as close to the viewport as possible. To keep the lamp-to-viewport distance to a minimum additional heat had to be extracted from the light beam. To this end, a flat dichroic mirror was interposed in the path of the light beam to further reduce direct radiation of infrared rays from the filament. Thus, the mirror reflected the visible light at a right angle into the viewport. Figure 10 illustrates this arrangement. In this manner, the direct thermal radiation delivered to the viewport surface was reduced considerably.

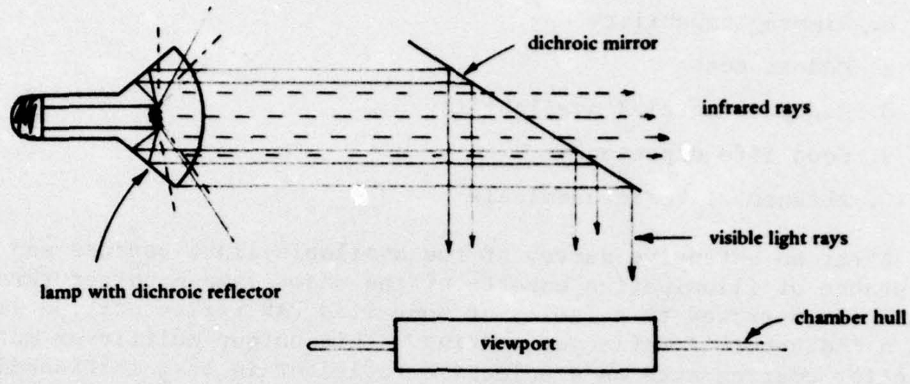

Figure 10. Use of dichroic cold mirror to reduce infrared input to viewport.

Figure 11 is a sketch of the first prototype of this system. Figures 12 and 13 show this prototype mounted on an instrumented simulated viewport installed in an oven door. The oven was maintained at a constant 90°F temperature to simulate the interior of a hyperbaric chamber; oven and thermocouple temperature readings were recorded on a strip chart as was the ambient room temperature. This test setup was used to evaluate experimentally the effectiveness of various systems for reduction of heat delivered to the viewport.

In these tests it was discovered that at high ambient room temperatures, the natural convective cooling was not adequate to carry off the waste heat from the EGL housing. To offset this effect, the heat input to the window (delivered through reradiated heat from the metallic components of the EGL system) and the heated air were further reduced by incorporating a small electric fan which blew the heated air away from the lamp and viewport area and ejected it through ventilation ports in the EGL housing.

Figure 14 shows the final design of the Mk 1 large viewport system as tested and evaluated in the field; Figures 15 and 16 show a typical installation of one of these units on a chamber. This unit utilizes standard 110-volt 60-Hz power for the lamp and the fan. A solid state dimmer switch is provided to permit lowering of light levels during periods when the chamber occupants are sleeping. The system incorporates a thermal switch (located in the conduit which supports the lamp socket) that automatically opens the power circuit to the lamp should the assembly exceed a temperature of 140°F.

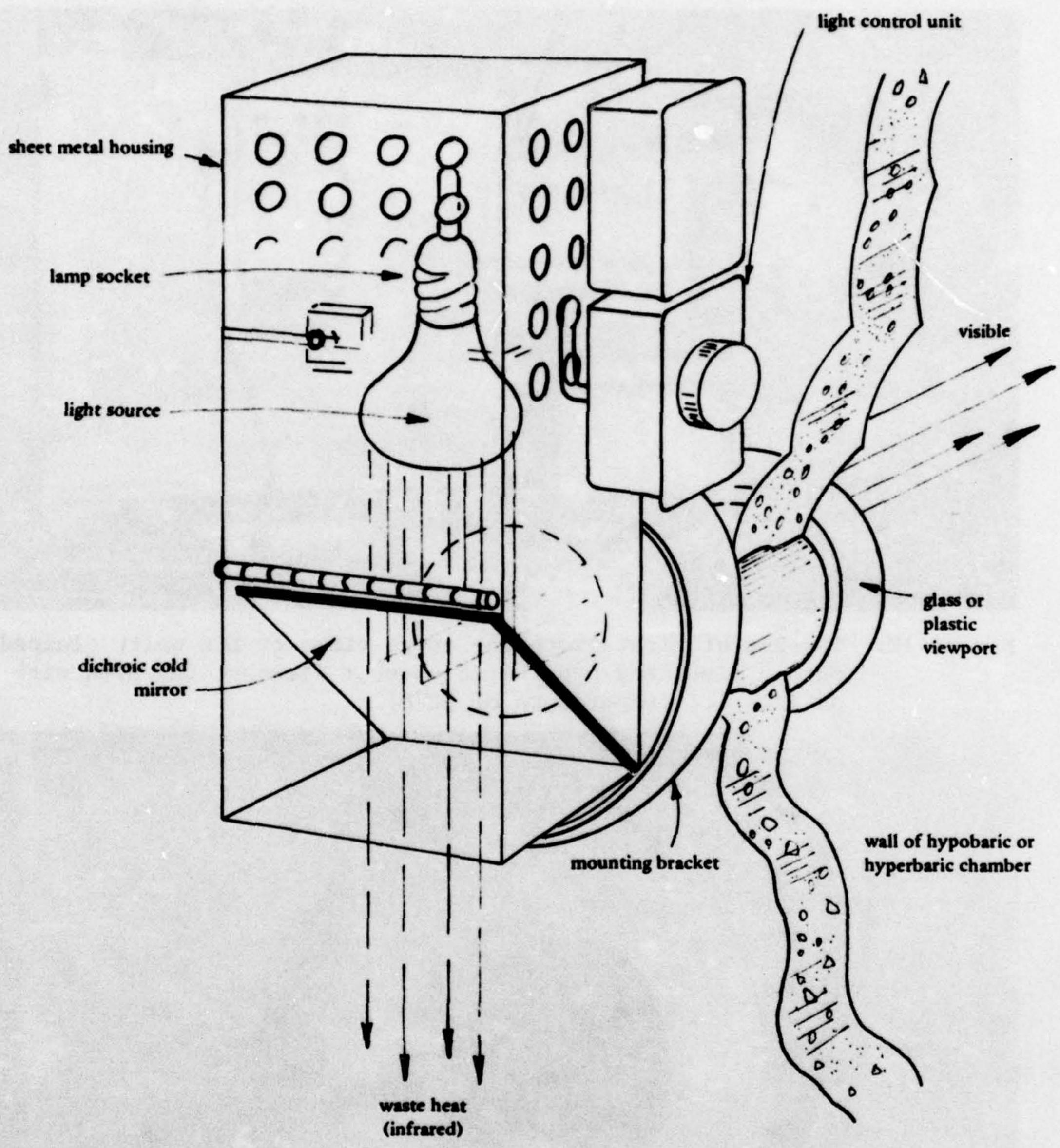

Figure 11. Conceptual sketch of the first large viewport EGL system showing basic components.

Figure 12. Testing of first prototype large viewport EGL unit, clamped onto a simulated hyperbaric chamber viewport (an oven with an interior temperature of 90°F).

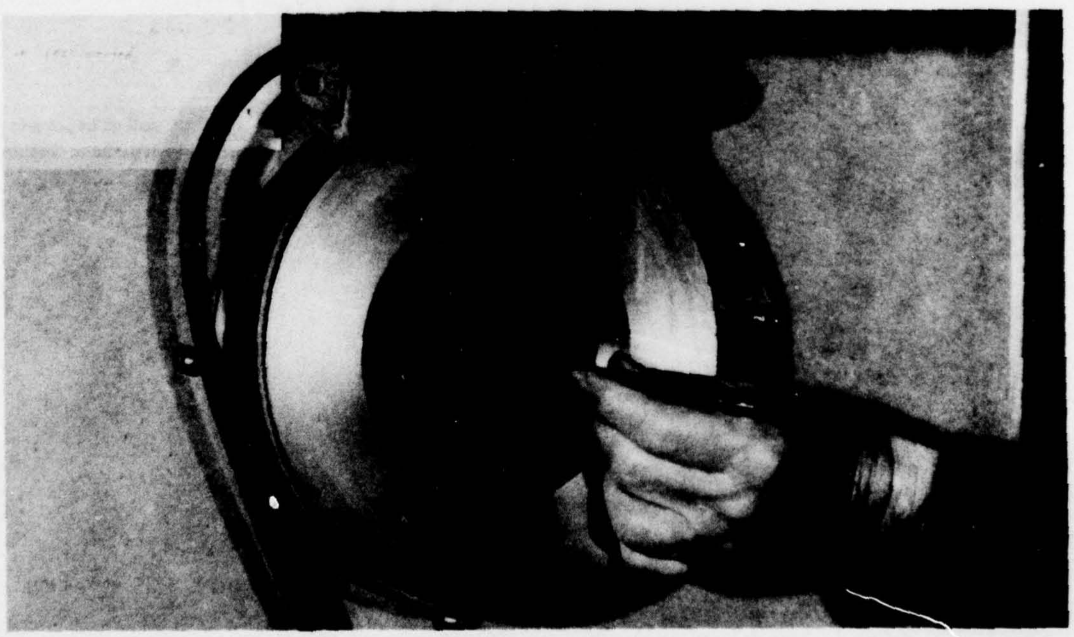

Figure 13. Pencil point on a junction of one of six thermocouples embedded in the 2-inch-thick acrylic viewport used to measure the thermal effects of various combinations of lamps, reflectors, fans, and component spacings on a simulated typical chamber viewport installation.

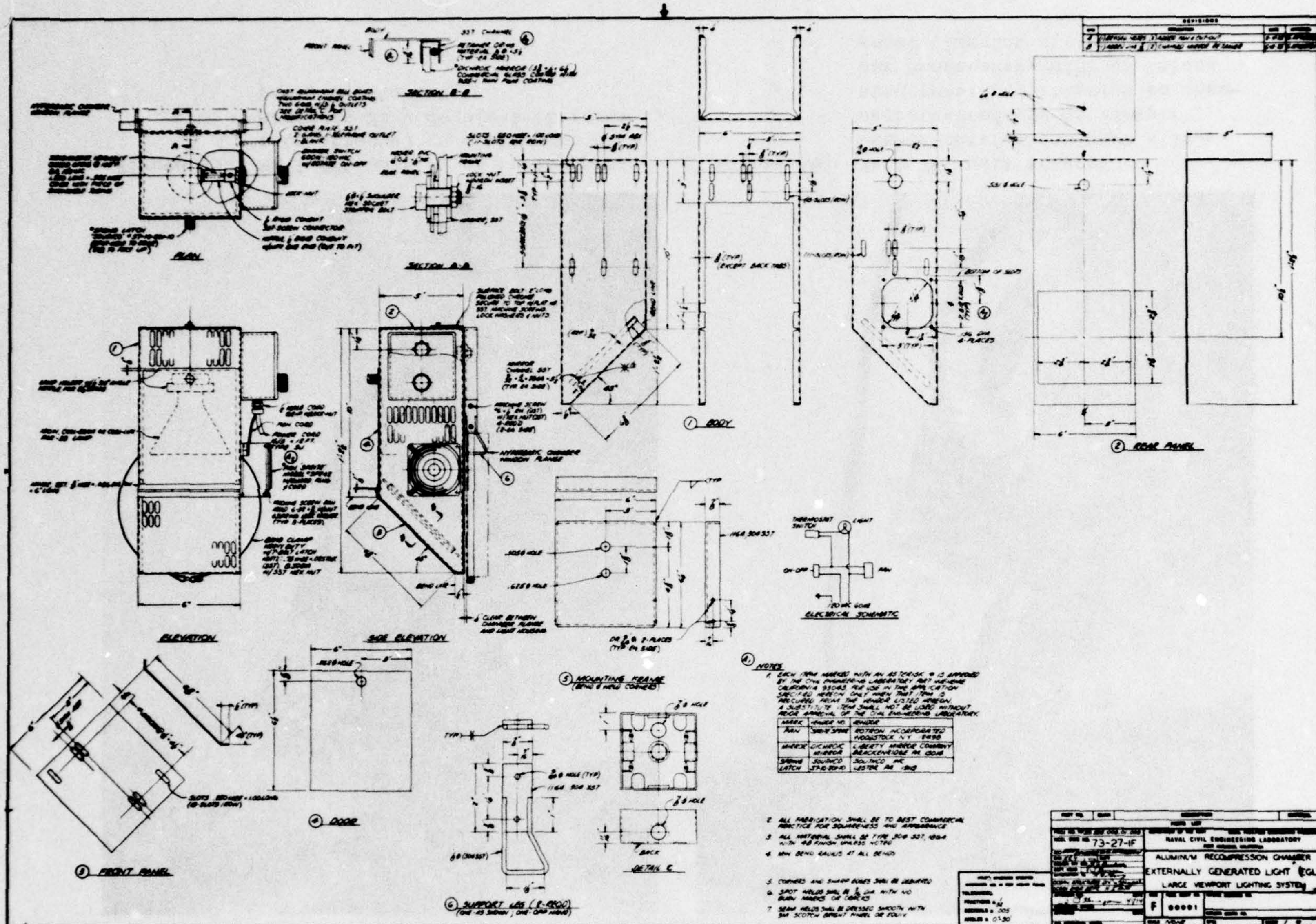

Figure 14. Final design of the Mk 1 large viewport EGL system as delivered for in service test and evaluation.

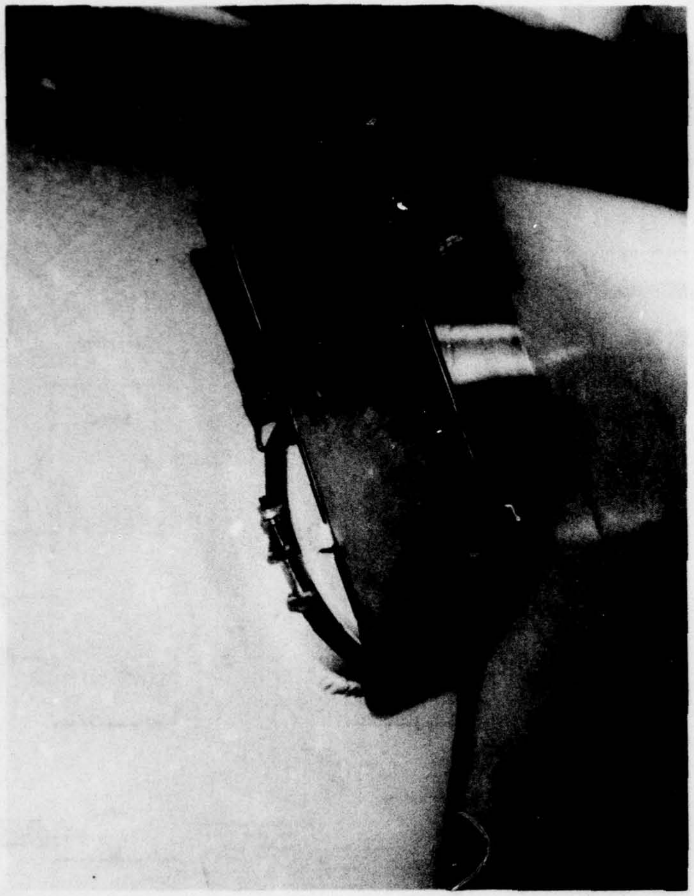

Figure 15. Mk 1 EGL unit in operating position attached to a viewport of a standard Navy double-lock recompression chamber.

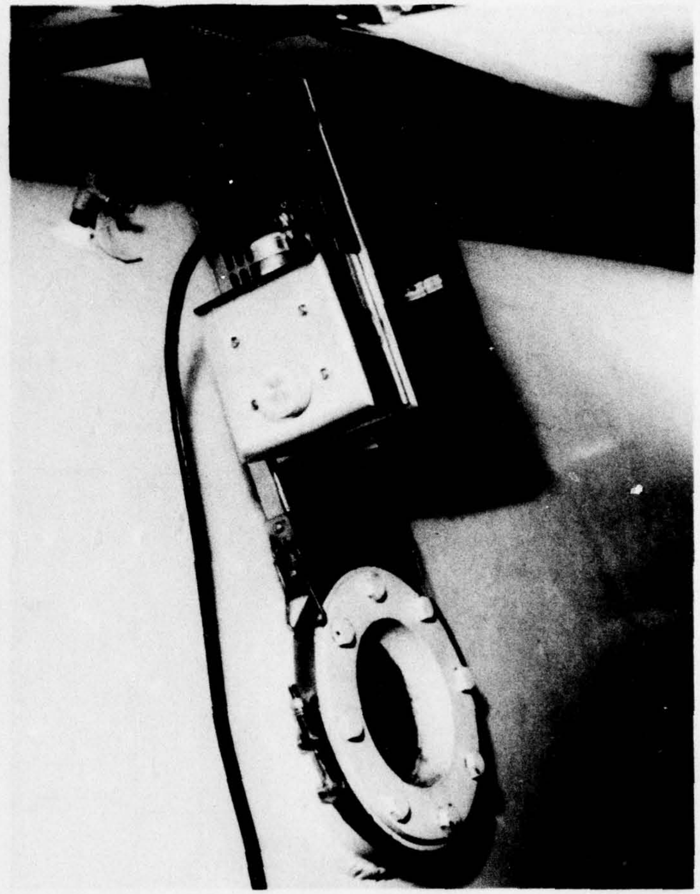

Figure 16. Mk 1 EGL unit rotated to out-of-service position allows unobstructed use of viewport; structural modification to chamber unnecessary with stainless steel clamping arrangement.

The mounting system utilizes a stainless steel strap-type clamp, designed so that it can be removed and replaced with different mounting adaptors for other applications. The mounting system is designed so that the unit may be unlocked and rotated 180 degrees into a vertical (upside down) orientation to permit free access to the viewport. Such unlocking and rotation requires no tools and can be accomplished in a matter of seconds.

The hinged cover on the back of the housing permits easy access for replacement of burned-out lamps without removing the unit from the chamber.

The housing is fabricated from stainless steel and requires no painting or other maintenance.

Maintenance and Repair

Only dichroic reflector PAR-38 lamps FSN 6240-958-6656 or FSN 6240-958-7161 (identifiable by the GE ''Cool-Beam'' or Sylvania ''Cool-Lux'' trade names marked on them) should be used. Any other lamps may overheat and break the mirror or damage the viewport. These lamps can also be visibly differentiated by looking through them at a strong light source; the light source should be dim and have a reddish hue. Other similar appearing lamps, which might be confused with dichroic reflector lamps, have aluminized reflecting surfaces that will either be completely opaque or, if semitransparent, will not give the observed light a reddish hue.

The dichroic mirror located opposite the viewport opening should be cleaned only with clear water and mild soap; abrasives or other types of cleaners may damage it.

The assembly drawing and the operating instruction sheets delivered with the units provide identification of the make and model of all proprietary components. The Appendix contains the operating instructions delivered for use with the Mk 1 system.

Mk 2 Water-filled Hyperbaric Chamber (Wet Pot) EGL System*

Externally generated illumination in the water-filled hyperbaric chambers (wet pots) required for diver training at the Naval School of Diving and Salvage, Washington, D. C., prompted modification and enlargement of the Mk 1 EGL design. Figure 17 illustrates the Mk 2 concept. The overall system differed from the Mk 1 in size, lamp power, and accessory conical acrylic mirror (CAM) unit used to distribute the light radially within the chamber.

The light source chosen was a 300-watt GE Cool-Beam dichroic reflector lamp. The increased heat load of this larger light source required additional measures to extract the infrared radiation accompanying the visible light. Since the spaces adjacent to the wet pot viewports used for illumination were less crowded than other areas surrounding the chamber, a larger light housing was practical to build for additional heat extraction systems.

*U.S. Patent no. 3,984,673 of 5 Oct 1976.

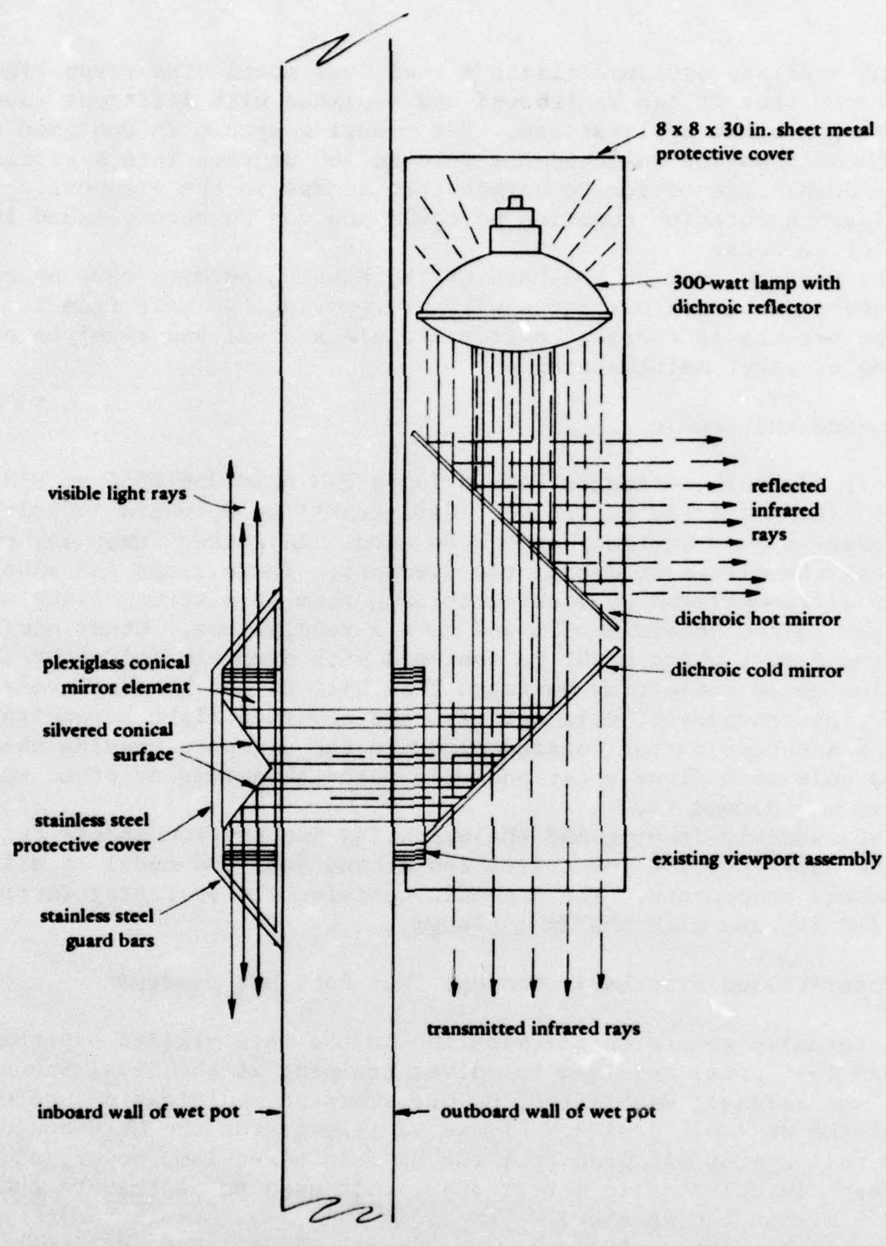

Figure 17. Conceptual sketch of the Mk 2 wet pot EGL system showing light generation and heat extraction systems and the conical acrylic mirror (CAM) unit used inside the chamber to radially distribute the light.

The first approach (Figure 17), was to utilize a dichroic ''hot'' mirror between the light source and the ''cold'' mirror. The hot mirror would reflect the infrared rays away from the chamber while at the same time allowing the visible light to pass through and impinge on the cold mirror. The cold mirror would in turn pass the remaining infrared rays and allow them to be ''dumped'' while at the same time reflecting the visible light through the viewport.

One problem with use of a hot mirror was that the dissipation of the heat through the outboard side of the light housing would necessitate use of guards to protect personnel from being burned. In addition, the reliance on convective cooling might present problems in the hot and humid environment where many of the wet pots are located. Also, the hot mirrors are another special order, relatively high cost, and fragile item.

Though the concept was workable and efficient, the practical disadvantages noted led to use of a motor-driven blower as the supplementary heat-dissipation device. The fan used is an inexpensive unit commonly used in cooling electronic equipment and available commercially. Further, minor mounting modifications make it feasible to substitute any available fan which will provide the same air movement.

Conical Acrylic Mirror (CAM)*

The truly unique feature of the Mk 2 system was the development of the CAM concept (see Figure 17) to overcome some of the problems inherent in working underwater with artificial light in a small space. The problems are (1) the visual interference (backscattering) when light reflects from particulate matter and gas bubbles entrained in the water and (2) the glare when facing the light source. This last problem is, of course, aggravated in a wet pot because of the severely limited working space.

In the CAM concept a mirror received the beam of light coming through the viewport and evenly distributed it along the inside walls of the wet pot. Since most wet pots are painted white on the inside, this made a fairly effective way of diffusing the illumination. Since the reflective surface of the CAM bent all light 90 degrees, the CAM was opaque to a viewer looking at its inboard side. It is possible, therefore, to look directly along the axis of a CAM-equipped viewport, as well as the axis of the light beam being introduced through that viewport, and not be blinded by glare.

In accordance with the EGL design guidelines set down early in this program, the entire EGL system could not affect the integrity of the pressure boundaries of the chamber in which installed. Therefore, the CAM mounting system required attachment or removal from the inboard side of a viewport penetration without disturbance of the installed viewport. Fortunately, the wet pots in use at the Navy School of Diving and Salvage, for which this system was designed, had integral inboard mounting hardware (studs) intended for steel viewport covers. The hardware developed at CEL utilized these threaded studs for securing the CAM to the hull. Figure 18 shows the assembled CAM unit. The mounting system incorporated a stainless steel guard designed to protect the CAM from damage and at the same time to prevent snagging a diver's hoses or damaging his suit with sharp corners.

*U.S. Patent no. 3,984,673 of 5 Oct 1976.

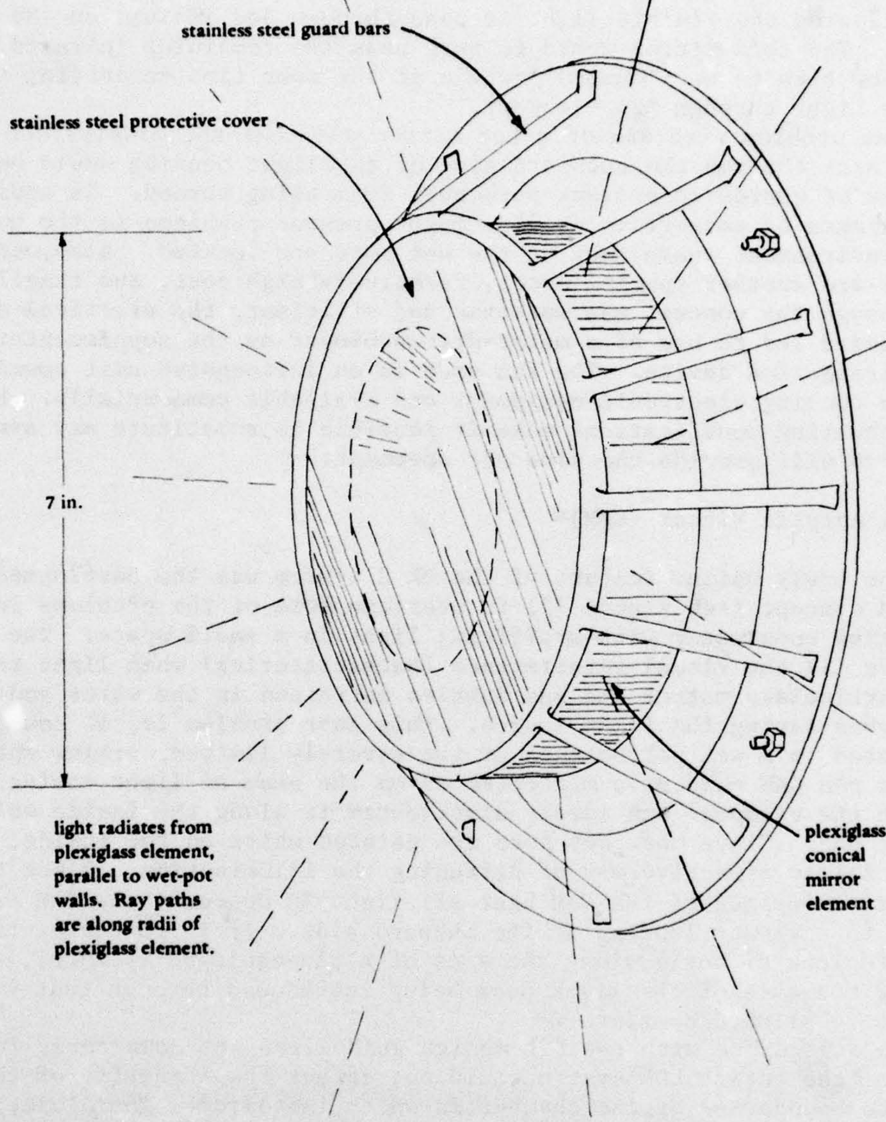

Figure 18. CAM system designed to diffuse light introduced through large wet pot viewports by distributing it radially within the chamber.

The principle of the CAM unit is applicable to hyperbaric chambers other than wet pots. While other chambers filled with gas do not have the problem of backscattering from suspended particulate matter, they do have the problem of the annoying, blinding spotlight effect of a light beam entering through the viewport. The disadvantage of using the CAM or any other inboard-mounted light deflector or diffuser is that the personnel outside of the chamber are denied use of such diffuser-equipped viewports for monitoring the welfare and safety of the chamber occupants.

One prototype Mk 2 wet pot unit was fabricated, bench-tested and shipped to the Naval School of Diving and Salvage for in-service test and evaluation.* Figures 19 and 20 give the design details of this system.

Mk 3 Emergency/Utility EGL System

Early in the development of the NAVFAC program, a working relationship was established with the staff of the Ocean Simulation Facility (OSF), at Naval Coastal Systems Laboratory (NCSL), Panama City, Florida. This relationship was particularly useful in the development of specific requirements for acrylic viewport and EGL systems. The emergency/utility (E/U) EGL system described here is an example.

The original basic requirement was to provide light that would operate only when the normal lighting system became inoperative. The probability of such occurrences was considered to be high at OSF because of the disruption of power support systems due to occasional hurricanes at Panama City.

The contractor provided the OSF complex with an emergency lighting system. This system, utilizing 25-watt 32-volt lamps mounted in housing attached to the outboard side of selected overhead viewport, satisfactorily performed its primary function of providing emergency lighting. However, during development of the acrylic light pipe (ALP) EGL systems, described elsewhere in this report, it became apparent that the ability to utilize the overhead viewport would be highly desirable for normal illumination, rather than simply for emergency light use. Superposition of this additional function on the original emergency lighting fixture was not practical; thus, a new approach was required.

The large OSF viewports for emergency lighting had an inside diameter of 5 inches. This was large enough to adequately utilize the output of the 150-watt PAR lamp with dichroic reflector used in the Mk 1 EGL system. The primary difference between the E/U EGL requirements and those of the Mk 1 EGL system was that the E/U system must be able to switch from 115-120-volt 60-Hz power to 28- or 32-volt DC power with minimum effort. The problem was formalized in discussions with the OSF staff, and the following general requirements for the optimum E/U EGL system were specified.

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*No data on in-service performance is available as yet.

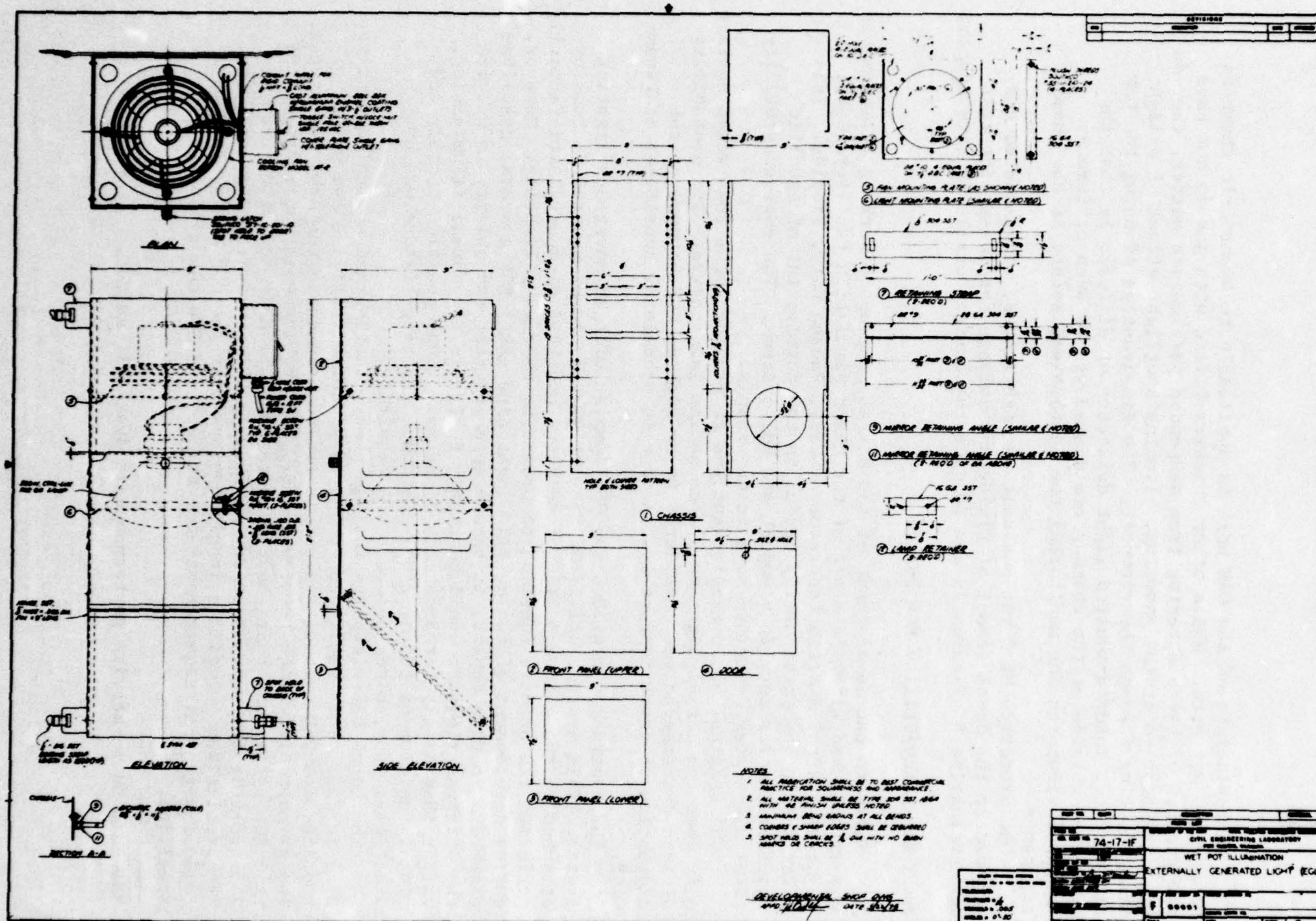

Figure 19. Mk 2 EGL wet pot large viewport lighting unit construction details.

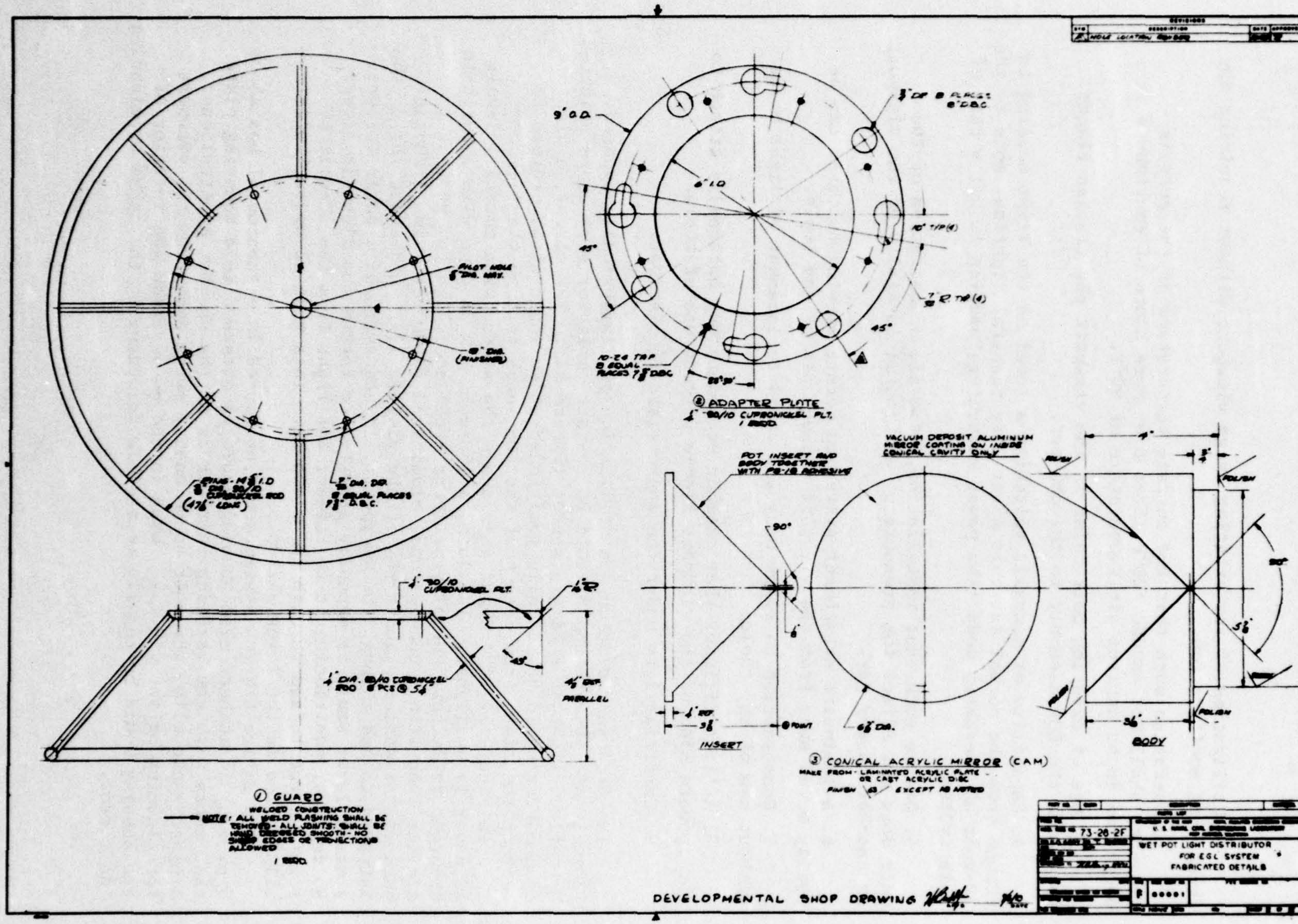

Figure 20. Conical acrylic mirror (CAM) light distributor and protective ground for Mk 2 wet pot EGL unit.

1. Utilization of any existing large viewport without requiring any structural modification.

2. Operation such that the surface temperature of the acrylic viewport shall not exceed 120°F after 8 or more hours of continuous operation in an ambient air temperature of 90°F.

3. Use of existing bolt holes in the viewport penetration flange to secure the EGL assembly to the chamber.

4. Capability of manually switching a lever on the light housing to change from the normal 120-volt AC utility (general lighting) mode to the 32-volt DC emergency mode (the power switching function is not a part of this system).

5. Design such that installation, removal, or operation of the unit does not affect the pressure or structural integrity of the viewport or chamber in any way.

6. A luminaire attachment system to permit viewing but that can be easily moved away from the viewport without use of any tools.

7. Construction to allow easy and rapid replacement of light bulbs without use of any tools.

8. A light diffuser that chamber occupants may optionally attach to the inboard side of the viewport flange without use of tools.

9. Certifiability under the appropriate regulations.

The proposed solution was utilization of diametrically opposed 120-volt AC 150-watt and 32-volt DC 25-watt reflector spot lamps oriented to reflect light at a single mirror (Figure 21). The mirror, a dichroic cold mirror would be manually positioned at an angle of 45 degrees to reflect the light from either of the two lamps through the viewport.

In Figure 21, the upper view shows the system when normal 115-volt AC power is available. The lamp, a 150-watt PAR 38 type with a built-in dichroic reflector, normally delivers about one-third the heat of a similar lamp with a conventional aluminized reflector. The dichroic cold mirror reflects about 90% of the visible light and about 10% of the infrared to and through the viewport. In the event of a power failure, a small lever would be manually operated to rotate the dichroic mirror 90 degrees, positioning it to reflect the light from the 32-volt DC light source to and through the viewport. This mode of operation is illustrated in the lower sketch.

The entire E/U EGL system would be housed in a sheetmetal box about 5 by 5 by 24 inches. The housing would be attached to a mounting plate that mates with the existing bolt circle on the chamber penetrations. A hinge would allow the unit to be easily swung away from the viewport for cleaning or for viewing. When in the up position the interior of the housing would be readily accessible for changing the lamps or cleaning the mirror.

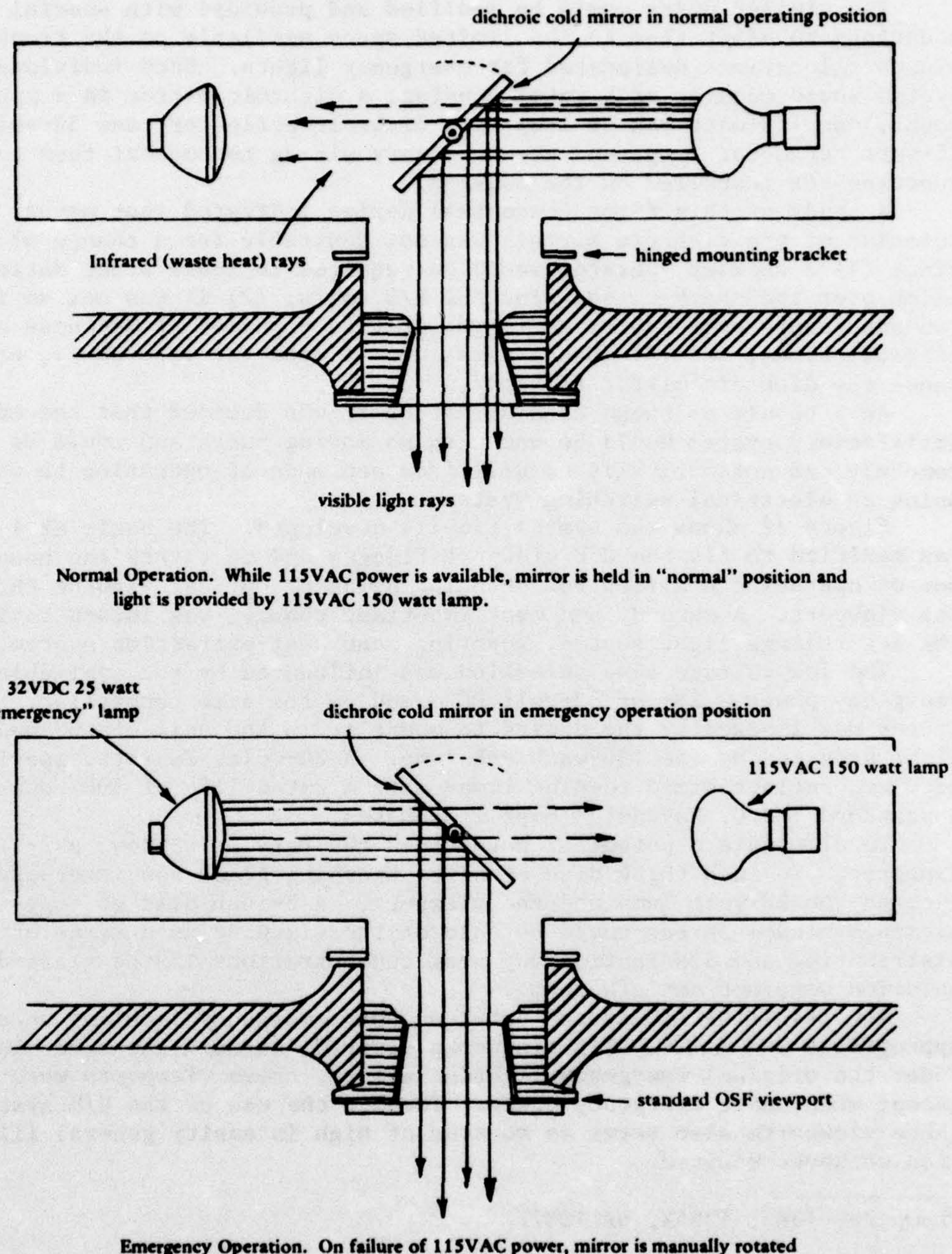

Figure 21. Original concept for the Mk 3 emergency/utility lighting system proposed for the NCSL Ocean Simulation Facility.

Two similar units would be modified and provided with special mountings to adapt them to the limited space available on the trunk viewport locations designated for emergency lights. Each individual system would consist of a metal housing, a dichroic mirror in a pivot mount, one 150-watt PAR 38 lamp with dichroic reflector, one 32-volt DC 25-watt reflector lamp, and the necessary wiring to connect them to a junction box installed on the housing.

A study of this first conceptual design indicated that manual rotation of the dichroic mirrors was not desirable for a change of mode since (1) a chamber operator would be required to leave other duties, climb over the chamber, and find the E/U units; (2) it was not an instantaneous change-over system and might provide a period of darkness at critical times; and (3) manual rotation, if done too vigorously, could cause the dichroic mirror to break.

As a result of these considerations it was decided that the most satisfactory system would be one with no moving parts and could be changed remotely and automatically at will from one mode of operation to another, using an electrical switching system.

Figure 22 shows the system finally developed. The basic Mk 1 system was modified to fit the OSF viewport flanges and to rotate the housing out of operating position for changing bulbs or optical viewing through the viewport. A second, and most important change, was incorporation of the low voltage light source, mounting, and heat-extraction system.

The low voltage lamp selection was influenced by the available emergency power - 28- or 32-volt DC - and by the size constraint. The latter was imposed by the desire to mount it in the axis of the beam of light provided by the 150-watt PAR lamp. A 28-volt, 20-watt, special service, reflectorized reading lamp* with a rated life of 300 hours and a standard ''S.C. Bayonet'' base was chosen.

To eliminate a potential hotspot on the acrylic window, a 2-1/2-inch-diameter, 1/4-inch thick disc of heat-absorbing glass was interposed between the 28-volt lamp and the viewport. A 5-inch disc of copper or aluminim window screen could be laid on the viewport as a means of distributing and dissipating any heat concentrations if the glass-disc solution were not satisfactory.

The resulting E/U system provides both emergency lighting when appropriate and utility lighting when desired, through the same viewport. Under the original emergency lighting system, these viewports were dark except when under emergency power. Through the use of the E/U system these viewports also serve as sources of high intensity general illumination whenever desired.

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*Lamp no. 1385, 1385X, or 1387.

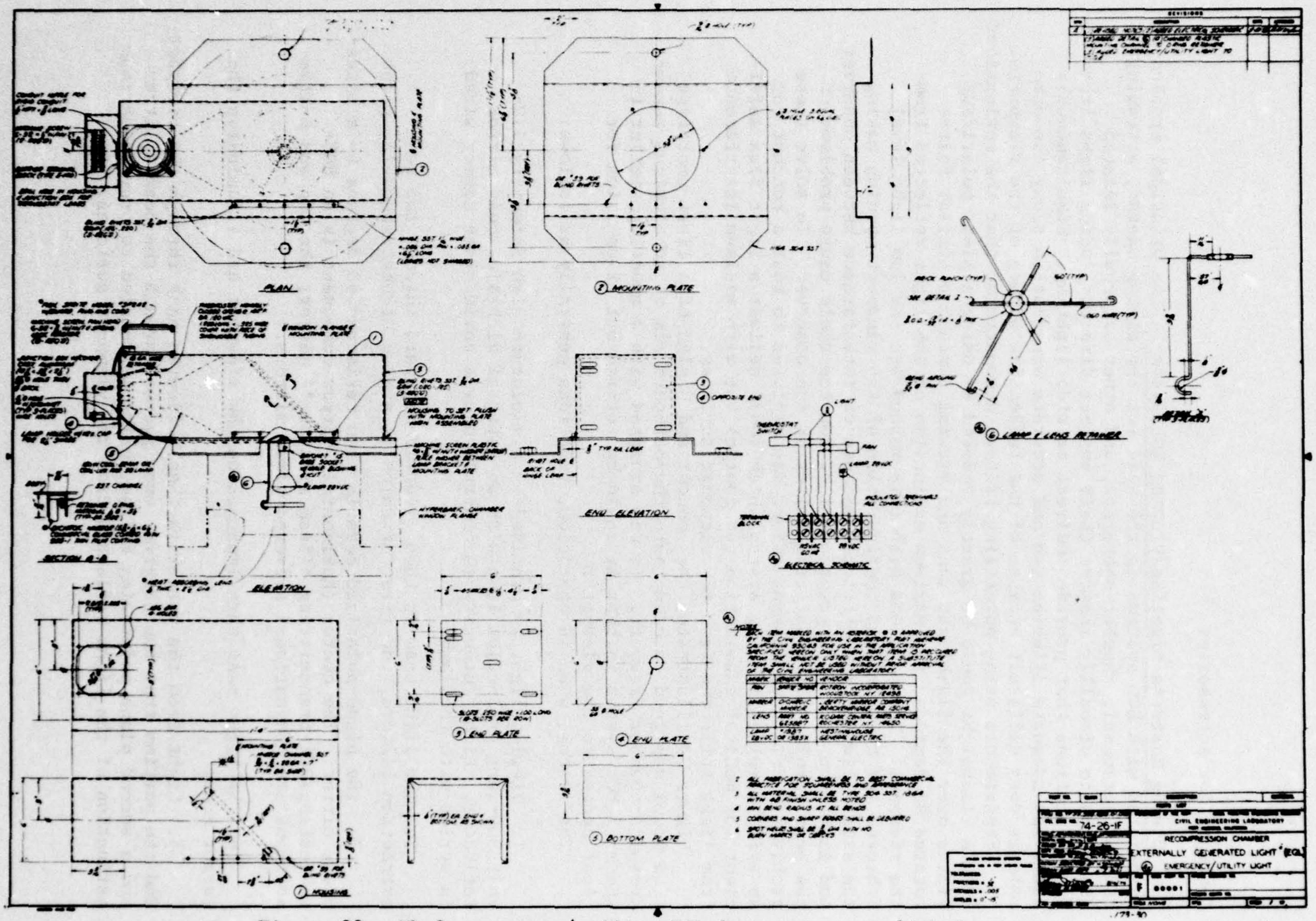

Figure 22. Mk 2 emergency/utility EGL large viewport lighting system developed for NCSL Ocean Simulation Facility.

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Concepts for Accessories

Diving Master's Lighting/Viewing EGL System. The principal problem associated with EGL systems is the need for the diving master, attending medical personnel, chamber operators, and other externally located observers to visuallly observe their subject directly, using light from fixed locations that provide indirect or side lighting. Simultaneously achieving adequate illumination and accurate observation along the same axis is very difficult because of the reflective nature of the viewports.

Experiments using polarizing filters demonstrated that the reflections from a flashlight could be greatly reduced by using a plane polarizing filter over the flashlight lens and viewing through a similar filter rotated 90 degrees for maximum extinction of the light reflected from the viewport. The problems with this method are the low light level achieved and the size and configuration of the viewport opening making the axial illumination difficult because of interference between observer and light source. More powerful light sources could cause problems of the heat burning the polarizing filter or the observer. To solve these problems a brief development effort was explored to test a concept for an axial viewing/lighting system which would deliver a light flux sufficient for medical examination and control but with minimum interference from light reflected from the viewport surfaces.

Figure 23 illustrates the concept and design of a first prototype of a model designed to clamp onto the outboard rim of an aluminum recompression chamber viewport. It was equipped with a mounting similar to the Mk 1 EGL system in that it could be rotated out of position for clear access to the viewport.

The system, when in operation, functions generally as follows:

1. Viewing light is provided by a miniature high intensity 110-volt 300-watt projection lamp with an integral dichroic, cold mirror reflector. Light intensity is controlled by a solid state dimmer wired in series with the lamp.

2. The light beam is then directed downward through two heat-extraction filters, the first of which is a disc of heat-absorbing glass.

3. The plane-polarized beam is then reflected 90 degrees by a three-piece mirror. The center (horizontal) mirror component is an 80%-reflecting/20%-transmitting ''beam splitter'' mirror; the top and bottom sections are conventional silvered glass mirrors.

4. The light beam then impinges on the viewport and illuminates the target area.

5. Light from the target is then reflected back through the viewport and the portion that the observer uses passes through the beam splitter and a second plane polarizing filter, which is rotated to provide maximum extinction of the light reflected from the viewport surfaces.

The heat-extracting filters in the light beam serve the function of protecting the polarizing filter from damage. Additional thermal protection is provided to the system by a fan controlled by a thermal switch which turns on the fan whenever it senses a temperature over 120°F. The fan and thermal switch bypass the dimmer control so that the fan is always operated at full power.

The prototype system performed generally as expected and adequately demonstrated the feasibility of the concept. Experimental evaluation of the system on actual hyperbaric chamber viewports revealed one unresolved problem. The optical qualities of the very thick chamber viewports were such that the plane-polarized light beam impinging on the viewport front surface was partially depolarized by the viewport material when it was reflected by the back surface and the target. The net result was an inability to achieve the desired degree of extinction of the unwanted reflected light. These unwanted reflections interfered with observation of the target area.

Since this application of EGL lighting was a spinoff of the major EGL effort, this exploratory development was not pursued further.

Fiberoptic ''Trouble'' Light. The desire to provide chamber occupants with a nonelectric ''flashlight'' led to a brief exploration of the utility of fiberoptic systems as a means of piping light from a viewport to some other location when desired.

A light collector and fiberoptic light pipe system (Figure 24) was conceived and a first prototype constructed (Figure 25). This system was designed to be used in a standard aluminum recompression chamber without any physical alteration of the chamber or any of its components.

The Fresnel lens was chosen for light collection on the basis of its off-the-shelf availability at modest cost. It was 2 inches in diameter with a focal length of 2 inches.

The lens/light-pipe mounting system positioned the end of the fiberoptic bundle precisely at the focal point of the lens. The fiberoptic bundle chosen was a commercially available glass-fiber medical unit in common use. The mounting assembly was fabricated from plexiglass so that use of the system would not materially interfere with the general illumination from the viewport on which it was installed.

In use, the large end of the unit was placed against the inboard side of a selected viewport and the locking nob turned until the unit was firmly wedged in the viewport flange. The fiberoptic bundle termination was then inserted in its socket and locked in place. An EGL unit was placed on the outboard side of the viewport and the light turned on; the system was then ready for use.

The system performed very well and was well-received by divers and medical personnel to whom it was demonstrated. This accessory was a spinoff of the major EGL effort, and further exploratory development was not pursued.

Further development would entail redesign of the system to utilize nonflammable materials in the lense and mounting system. The fiberoptic bundle can be manufactured or special-ordered with a nonflammable plastic jacket.

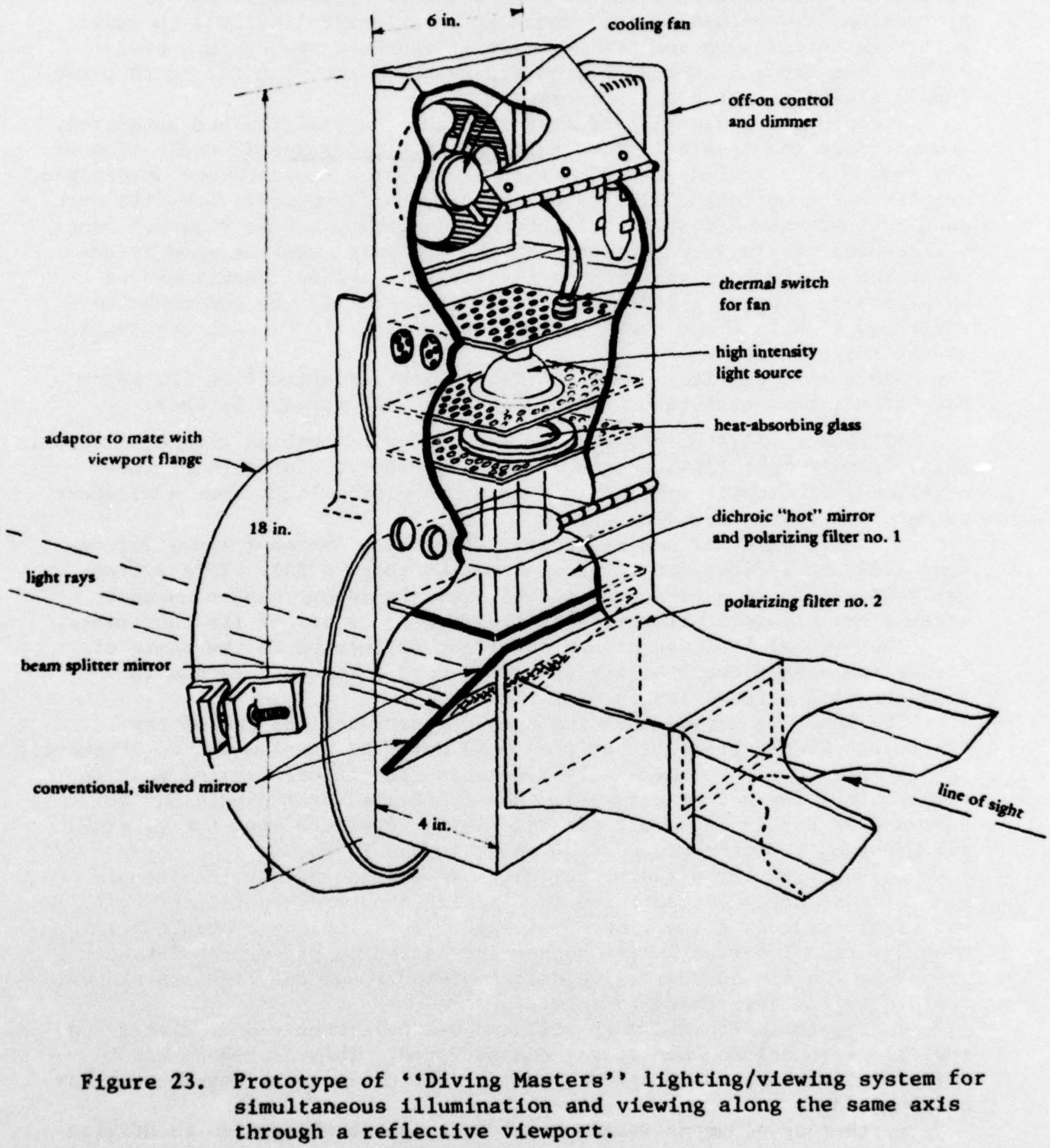

Figure 23. Prototype of ''Diving Masters'' lighting/viewing system for simultaneous illumination and viewing along the same axis through a reflective viewport.

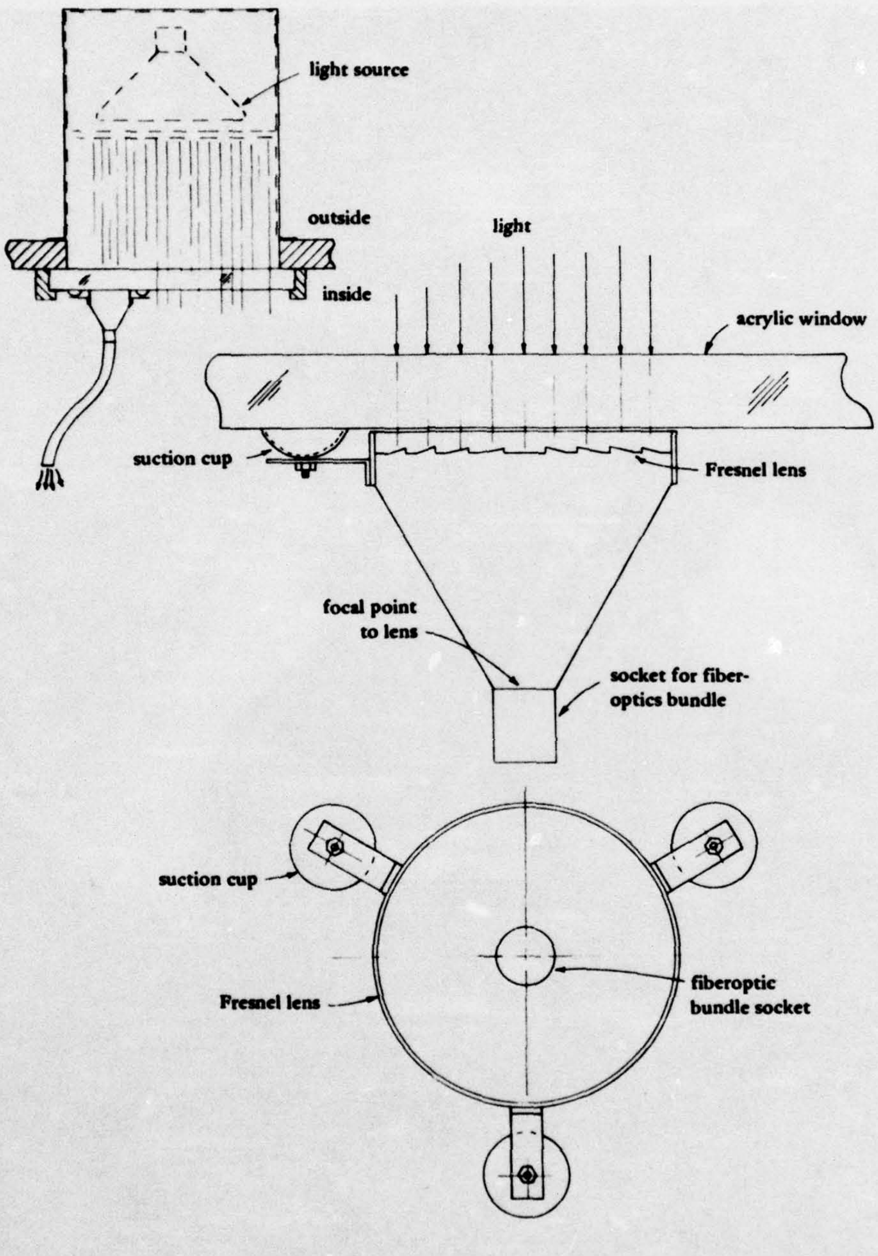

Figure 24. Conceptual sketch of light collector and fiberoptic light guide adaptor for fiberoptic trouble light system.

Figure 25. Prototype of fiberoptic trouble light system for use in hyperbaric chambers.

Diffusers. The problem of breaking up the spotlight-like beam that the EGL units project into the chambers was briefly considered. Diffusers located on the inboard side of the large viewports of most existing recompression chambers were not judged safe because any effective diffusing system attached to a viewport will prevent normal, as well as emergency, observation through that viewport. Also, in an emergency situation, chamber occupants would very likely be unable to remove the diffuser, and the outboard personnel could not do so.

In the case of aluminum recompression chambers, lightweight diffusers seem practical. These could be held in place by externally located magnets and would permit externally located chamber operators to drop them when necessary.

Through-the-hull Light Controls. The ability of chamber occupants to exercise some control over their lighting system is desirable in extended dives. Such systems must, however, be subject to override by the chamber operators for safety and operational reasons.

Feasibility of controlling EGL systems mounted on aluminum recompression chambers by use of magnets has been demonstrated. Sensitive magnetic reed switches can be mounted on the hull exterior and operated by powerful permanent magnets in the hands of the chamber occupants.

Chambers with steel hulls cannot use such a system; however, concepts for optical control through viewports and magnetic control through nonmagnetic, high-strength viewport blank covers have been considered and are believed feasible.

Since these concepts were spinoffs of the major EGL effort, no developmental work was carried out beyond a demonstration model of the through-the-hull control for aluminum chambers.

SMALL PENETRATION, ACRYLIC LIGHT PIPE (ALP) EGL SYSTEM DEVELOPMENT

The effort to develop EGL systems which could operate through small pipe-sized penetrations in a chamber hull was stimulated by several factors; foremost of these were:

1. All available viewports are needed for direct observation of the chamber occupants for control, monitoring, and safety. The number and location of viewports in existing chambers reflected the judgment of the original chamber designers as to the absolute minimum required for safe operation; therefore, the sacrifice of one or more of these for lighting necessarily reduces the safety factor to some degree.

2. Chamber alteration by installation of additional large viewports to illuminate the interior is not only very costly but puts the chamber out of service for a considerable time.

3. The incorporation of large viewports for illumination in new chambers is costly.

4. Most chambers have spare pipe-sized penetrations which could be made available for light introduction.

5. The addition of small penetrations is much simpler and less costly.

6. The hull area is much smaller for this type of pentration, which are, therefore, easier to locate in optimum locations.

A study of the two commercially available small penetration lighting systems and their component parts revealed that they were essentially functionally identical to the large viewport EGL systems previously described. Each utilized the same basic subsystems: (1) light control, (2) light generation, (3) heat extraction, (4) light direction, (5) pressure-resistant window in chamber hull, and (6) inboard light distribution.

The primary differences between the two small penetration systems and the large EGL system were the size and the configuration of the window element used.

The window element of the Perry Cold Light System (Figure 4) is an acrylic plastic unit that achieved its pressure seal by means of a 1-inch NPT male-threaded end screwed into a 1-inch NPT female receptacle.

The Canty Light System window element (Figure 7) was a part of a monolithic light pipe, conical window, and light distributor fabricated from one piece of acrylic plastic rod.

To provide design guidance to meet real operational and certification requirements as well as a test bed for evaluating the system, one of the OSF chamber pipe-sized penetrations was chosen as the model for which prototype hardware would be designed.

Requirements

The configuration of the OSF chamber penetration, shown in Figure 26 and identified in the OSF drawings as type ''J,'' placed certain controls on the shape and size of the ALP hardware. These constraints involved primarily (1) adaptation to the existing pressure sealing system, (2) the mounting, (3) matching of the outside diameter for the penetration reinforcement, and (4) utilization of the 0.96-inch-diameter clear opening for passage of the light flux.

Some specific requirements for a system useful in the OSF chamber were: (1) safety during long-term operation at 1,000 psi; (2) fabrication of inboard located components from materials certifiable under the applicable regulations (governing such things as flammability, toxicity, potential for outgasing); and (3) delivery of a sufficient flux of light to be useful in this particular environment.

Other design guidelines had been developed during the state-of-the-art study. These primarily concerned safety, maintainability of the system with minimum interruption of chamber operation, and flexibility in the use of the installed system.

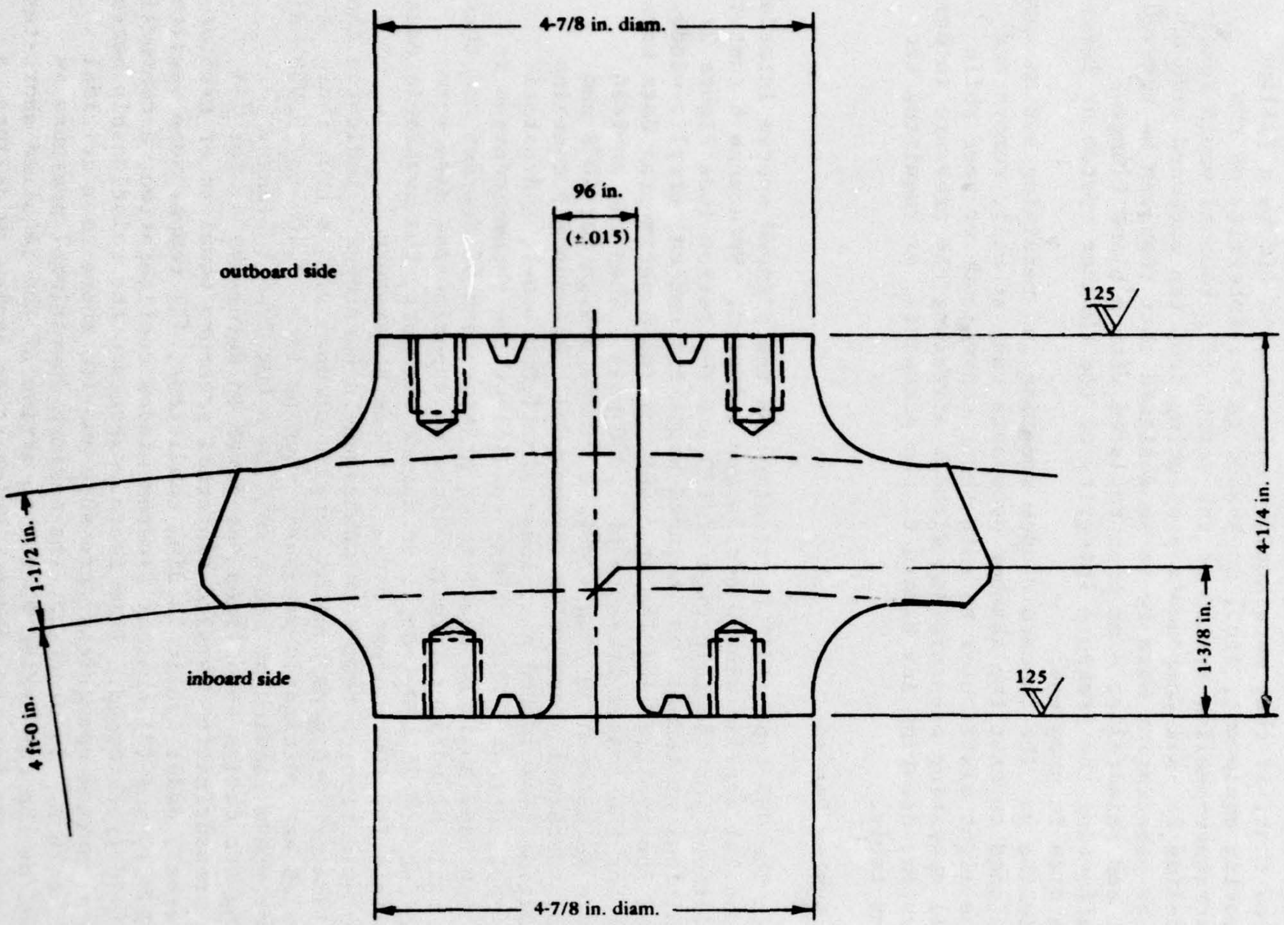

Figure 26. NCSL Ocean Simulation Facility chamber penetration type J for which the CEL acrylic light pipe EGL system was designed.

Guideline 1: All fragile components projecting from the inboard or outboard sides of the chamber penetration were to be so designed and constructed that, if they were accidentally sheared off by a falling object, moving equipment, etc., no hazard to the integrity of the chamber pressure-sealing system or the safety of personnel would result.

Guideline 2: All components projecting from the outboard side of the chamber penetration were to be so designed that they can be removed, repaired, and reinstalled - or even replaced with a blank flange - without affecting the pressure integrity of the chamber system or interrupting a dive in progress.

Guideline 3: The inboard window mounting and retaining system were to be designed so that the chamber occupants can, at will, remove and change the light distributor to suit their convenience or need while under full operating pressure and without affecting the pressure integrity of the system, creating any hazard to the occupants, or requiring the use of any tools.

Viewport System Design

Using the OSF type ''J'' penetration as the planned system interface, a small conical acrylic window design was selected. Reference 6 contains recommendations for the selection of t/D_i, D_i/D_f ratios (see Figure 27 for definitions of terms) and included angle for conical acrylic windows to be used for cyclical loading at 5,000 psi (no experimental data were available for the lesser pressure of 1,000 psi). When the ambient temperature is between 80° and 120°F, a window design for 70°F and 10,000 psi sustained pressure is recommended. Reference 5 contains recommendations for 10,000 psi, long-term (1,000 hour), hydrostatic pressure applications. Under these conditions the recommendation is that the included angle be equal to or greater than 90 degrees and that the t/D_i ratio be 0.75 or larger. Since no experimental data were available for a 0.75 t/D_i ratio, 90 degree viewport, the available data were examined for the closest match to these parameters.

An examination of test data contained in Reference 1 indicated that 1-inch-diameter 90-degree conical acrylic windows with a t/D_i ratio of 0.625 failed at hydrostatic pressures ranging from 27,100 to 29,900 psi under short-term loading at about 70°F in a DOL Type I flange.

Using the design guidelines set forth in Reference 11 for (1) internal pressurization service (internal pressure equal to or greater than external) under cyclic loading conditions, (2) temperature service (up to 120°F), and (3) conical frustum window configuration, a conversion factor of 10 is obtained. This factor expressed the relationship between a window's maximum operational pressure and its short-term critical pressure at 70°F. In practice, the maximum operational pressure is multiplied by the conversion factor to arrive at the required short-term critical pressure for the window. Using these design guidelines, a 1,000-psi operational pressure equates to a 10,000-psi short-term critical pressure. In the case of a 90-degree conical window, the minimum allowable t/D_i ratio would be on the order of 0.4.

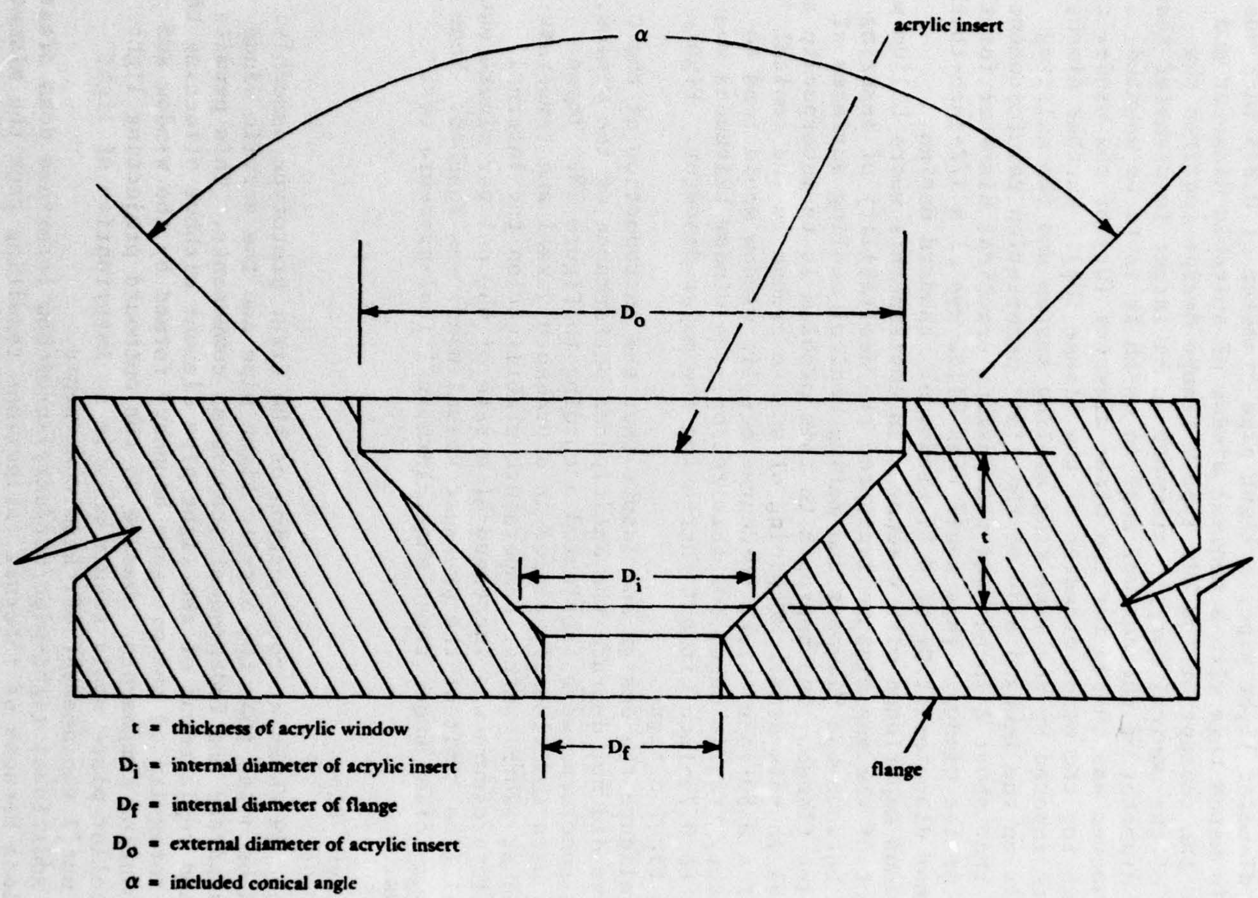

Figure 27. Definition of technical terms in conical acrylic window.

Because of the dimensional constraints imposed by the bore of the Type ''J'' penetration (0.96 inch) and the desire to use the largest practical diameter light pipe, a light pipe diameter of 0.875 inch was chosen. To match this with a conical window of suitable diameter and to conform to the concept of the DOL Type V flange design requires the small end of the conical acrylic viewport to be larger in diameter than the minor diameter of the conical seat in which it is to be mounted, a 1-inch diameter was chosen for the minor diameter (D_i) of the window and a 0.96 inch for the minor diameter of the flange (D_f). Further dimensional constraints imposed by the lens ring sealing system and the existing bolt circle on the inboard side of the ''J'' penetration reinforcement indicated that about 2 inches was the maximum practical diameter for the large end of the window. This would then allow use of a 1/2-inch-thick, 1-inch minor diameter (t/D_i of 0.5) window of standard design.

Previous experience with viewports in environments where helium was a component of the gas mixture indicated the desirability of insuring a good seal between the viewport and mating conical sealing surfaces of the mounting flange. One approach to this problem is to incorporate an O-ring seal in this area. Machining of such a groove in the conical surface of a 0.50-inch-thick, 90-degree acrylic window would tend to create a very fragile edge; for this reason, the window thickness was increased to 0.75-inch without increasing the major diameter. Figure 28 shows the final design.

To validate the design and insure that the introduction of the O-ring groove did not degrade the anticipated performance of the window, five test specimens were fabricated according to Figure 28. These specimens were individually placed in a pressure vessel and temperature stabilized at 120°F. After temperature stabilization the internal hydrostatic pressure was increased at a rate of 650 psi per minute until 20,000 psi (the limit of the pressure vessel used) was reached. None of the windows failed under these short-term, critical-pressure test conditions.

Acrylic Light Pipe

Figure 29 shows a cross section of the first prototype assembly. It should be noted that the acrylic light pipe and the acrylic window are two separate and independent structural components. This permits removal and replacement of the light pipe element without affecting the pressure integrity of the pressure boundary formed by the window and window-mounting components. Damage to the outboard projecting light pipe or collar plate would result only in an interruption of light delivery until replacement of these components.

The additional light-pipe/air/acrylic-window interface does create a light loss because of internal reflections resulting from the mismatch of indices of refraction between acrylic plastic and air. This situation is partially alleviated by thinly coating the light-pipe end with silicone grease. This procedure greatly reduces the reflective nature of this boundary area when the light pipe is pushed against the window and the intervening film of air is replaced by silicone grease.

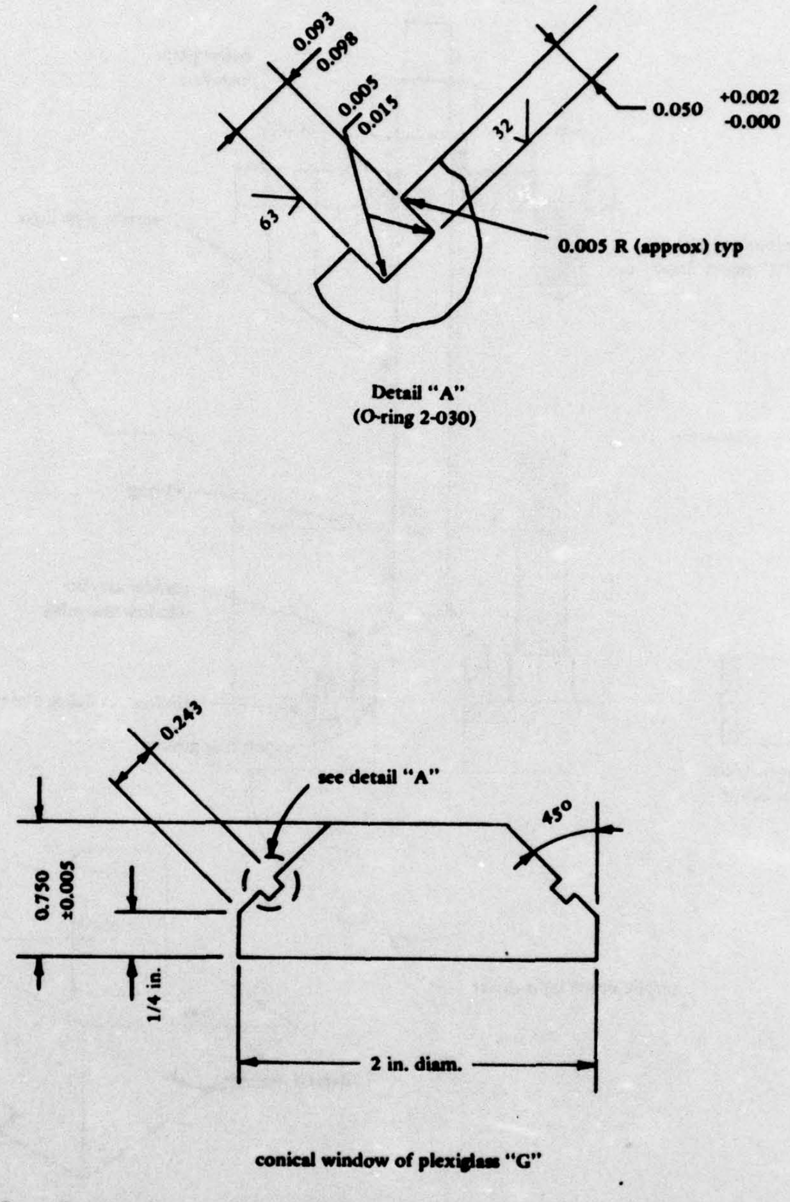

Figure 28. Conical acrylic window design used as pressure-sealing/light-transmitting component in Mk 4 acrylic light pipe EGL system for NCSL Ocean Simulation Facility.

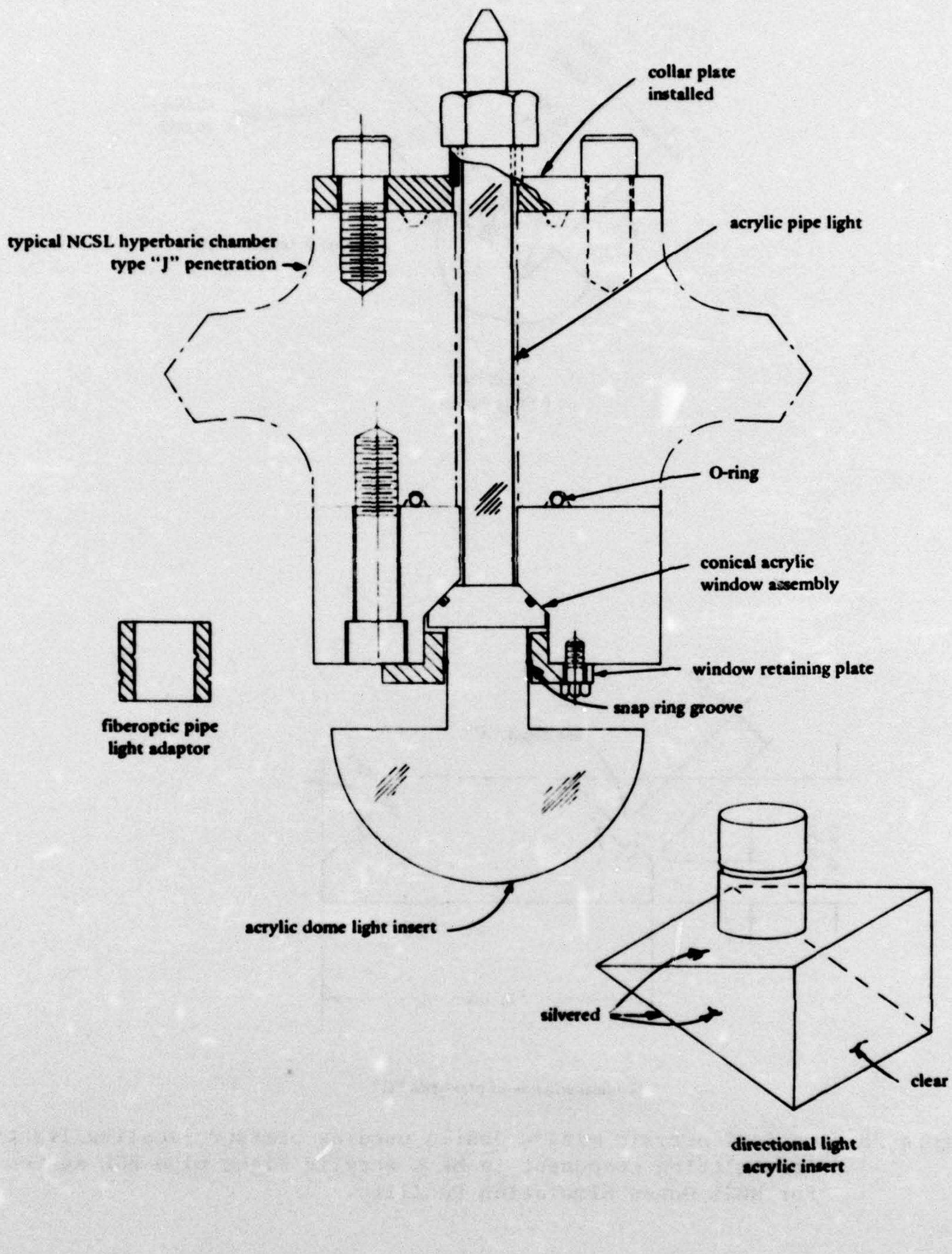

Figure 29. Conceptual sketch of prototype acrylic light pipe EGL system.

Light Source Selection

A brief study was made of potential light source designs, and it was decided that the light source component of the Canty light system provided the most cost-effective solution to this problem.

Prototype Installation

The prototype system was installed (Figures 30 and 31) in a simulated ''J''-type penetration at the OSF and a preliminary evaluation conducted.

Final System Development

The successful development of the first prototype completed the major milestone in this phase of the NAVFAC-supported exploratory development program. Feasibility was demonstrated, and the OSF staff requested CEL to submit a proposal for finalization of a certifiable design and procurement of 15 operational systems.

Under funding provided by NCSL, CEL refined the system and finalized the design as shown in Figure 32. Fifteen operational systems and spare parts were subsequently delivered to OSF.

The light distribution options shown in Figure 32 illustrate the three types delivered to OSF. Many additional options are possible since the window retaining plate will accept any type of distributor with a flat 1.120-inch-diameter base and a cylindrical shank 0.75-inch long or longer. This permits the design of bent acrylic light pipes for special purposes or adaptation to a fiberoptic light-guide distributor.

The type 1 distributor (see Figure 31), when in use, looks much like a small inside-frosted light bulb.

The type 2 distributor uses the 45-degree flat surface as a mirror and provides a means of directing the light at right angles to the axis of the window/penetration system. It can be rotated to any desired position.

The type 3 distributor uses a 90-degree conical recess as a conical mirror to radiate light equally in all directions normal to the axis of the window/penetration system.

All of the distributors reach maximum efficiency only when the distributor/window interface is coated with silicone grease so that no air film is trapped between the two surfaces. This grease film reduces internal reflections which otherwise would diminish the light output. The system can also be operated without any light distributor in place, thus producing a spotlight effect. The light may be dimmed by controlling the voltage to the light source.

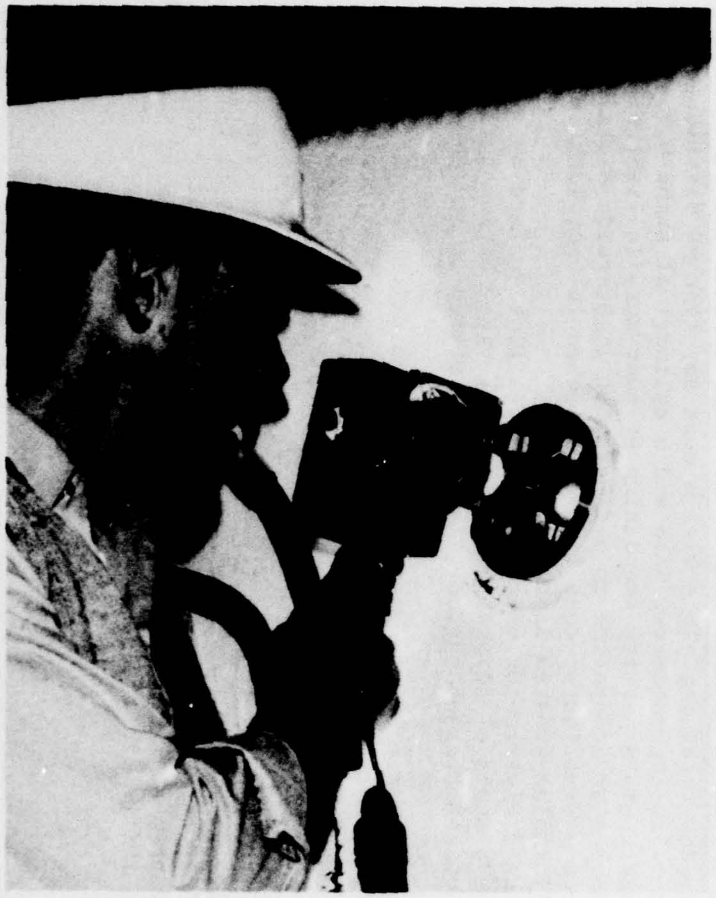

Figure 30. Prototype CEL acrylic light pipe EGL system installed in a J-type penetration of the NCSL Ocean Simulation Facility.

Figure 31. Inboard components of the CEL acrylic light pipe system with frosted light distributor installed in a J-type penetration of the NCSL Ocean Simulation Facility.

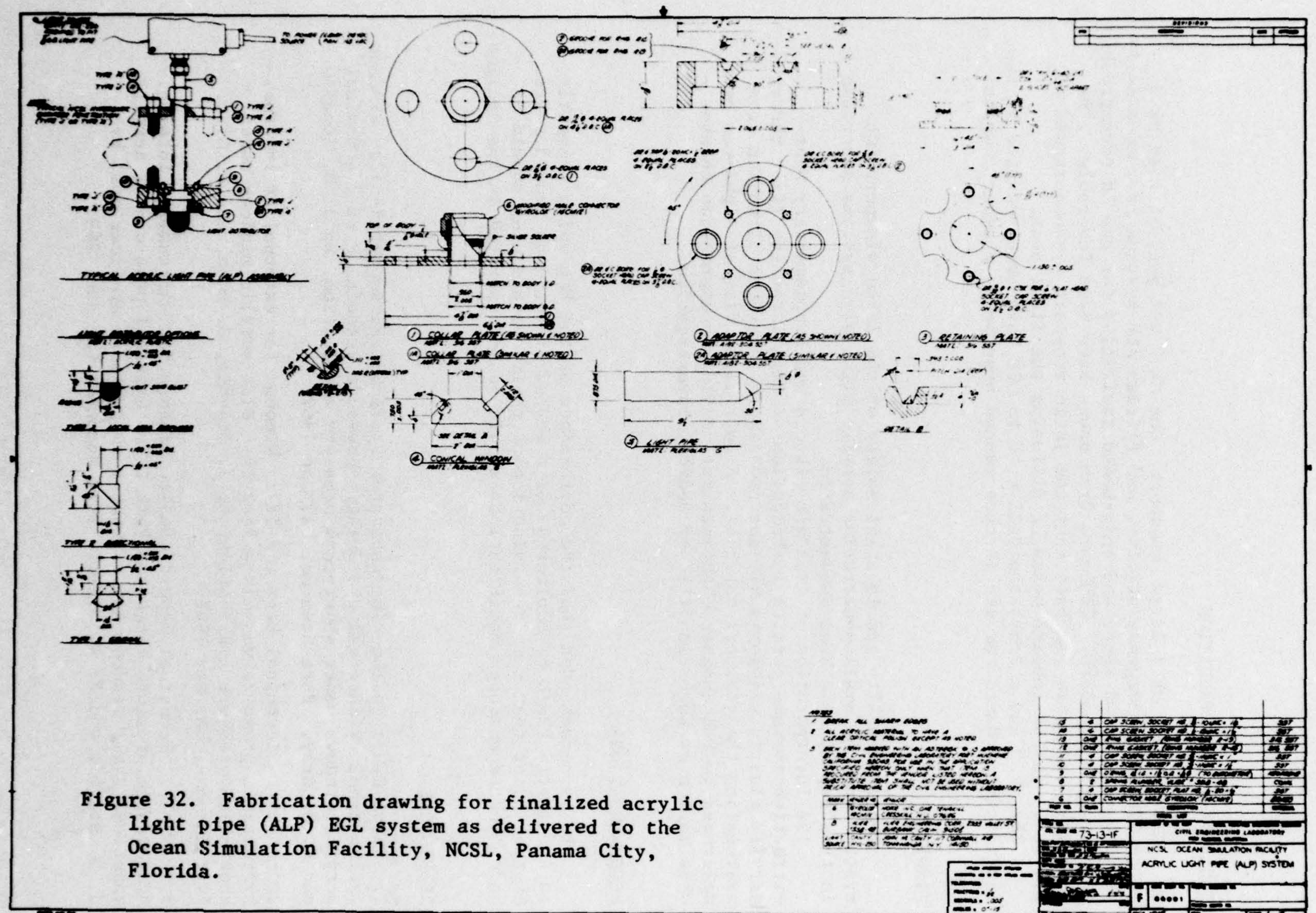

Figure 32. Fabrication drawing for finalized acrylic light pipe (ALP) EGL system as delivered to the Ocean Simulation Facility, NCSL, Panama City, Florida.

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FIELD TEST AND EVALUATION

Twenty-nine Mk 1 large viewport, one Mk 2 wet pot, fifteen Mk 3 large viewport emergency/utility, and fifteen ALP systems have been delivered to a variety of shore and ship-based facilities for use on recompression and research chambers. Comments from users have been favorable. The principal criticism has been that the large viewport systems should be provided with an inboard means of diffusing the light beam.

The Mk 3 and ALP systems delivered to OSF have been accepted by the Certification Board for use in that manned hyperbaric chamber complex.

FINDINGS

The feasibility and inherent safety of the large viewport EGL systems and the small penetration acrylic light pipe systems described in this report have been demonstrated.

The incorporation of dichroic mirrors and supplementary heat-extraction systems permits introduction of high intensity light through acrylic plastic viewports without creating a hazardous situation from overheating the viewport material. A sufficient flux of light can be delivered to the chamber occupants for routine recompression chamber observation or for scientific or medical investigation.

RECOMMENDATIONS

It is recommended that the performance of the EGL units presently in use in the field be monitored for a period of not less than 3 years. At the end of that time an evaluation of their performances should be made, and recommended modifications should be incorporated in the designs.

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Appendix

OPERATING PROCEDURE FOR Mk 1 EGL SYSTEM

1. Use only 120-volt AC, 60 Hertz power.

2. Any time fan fails to operate, turn light off until fan (Fan-Rotron ''Sprite'' Model SP2A2) is repaired or replaced; operation of unit without fan may damage the viewport.

3. Use only 150-watt, 120-volt PAR 38 lamp - Cool-Beam or Cool-Lux (FSN-6240-958-6656 or FSN-6240-998-7161). DO NOT USE STANDARD FLOODLAMPS OR SPOT LAMPS; use of the incorrect lamp will damage viewport and may cause it to fail.

4. Special 5-3/4 x 1/8 x 6-1/2-inch commercial glass mirror, coated with 955-1 thin film coating. Vendor is Liberty Mirror Company, Brackenridge, Pennsylvania.

WARNING

> The use of mirrors or lights other than those specified above will cause overheating of chamber window, with possible damage or blowout under pressure.

5. Temperature protection is provided by a thermal switch (normally closed) wired in series with the light. Switch is inside the 1/2-inch rigid nipple and is set to open at 140°F. Cycling of the light (OFF-ON) would indicate an overheated condition which could be hazardous to the safety of the chamber viewport. Corrective action should be taken to increase cooling capacity if this condition should exist.

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